U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-286 421

Review of Past Studies Addressing the Potential Impact of CO, HC, and NOx Emissions from Commercial Aircraft on Air Quality

Environmental Protection Agency, Ann Arbor, MI

Mar 78

AC 78-03
PB 286 421

Technical Support Report for Regulatory Action

Review of Past Studies Addressing the Potential Impact of CO, HC, and NOx Emissions from Commercial Aircraft on Air Quality

by

Philip Lorang

March 1978

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Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air and Waste Management
U.S. Environmental Protection Agency

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U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
AC 78-03		

4. TITLE AND SUBTITLE
Review of Past Studies Addressing the Potential Impact of CO, HC, and NOx Emissions from Commercial Aircraft on Air Quality

5. REPORT DATE
March 1978

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Philip Lorang

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air and Waste Management

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
1

12. SPONSORING AGENCY NAME AND ADDRESS
U.S. Environmental Protection Agency
2565 Plymouth Rd.
Ann Arbor, Michigan 48105

13. TYPE OF REPORT AND PERIOD COVERED
Tehcnical Support Report

14. SPONSORING AGENCY CODE
200/05

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Since 1973, EPA has monitored the progress of technology needed to meet the existing air quality standards for aircraft engine emissions and reviewed the impact of various classes of aircraft on ambient air quality. As a result, there is now in draft form an NPRM to amend the existing standards. During the preparation of the draft NPRM, several commenters questioned the air quality justifications for certain standards. This report is partial documentation of EPA's review of the past air quality studies, and also a review of air quality justifications for the commercial aircraft emission standards contained in the NPRM.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Aircraft Aircraft emissions Commercial aircraft Air quality standards	Air Air pollution Air standards	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release Unlimited	unclassified	73
	20. SECURITY CLASS *(This page)*	22. PRICE MF A01 PC A04
	unclassified	

EPA Form 2220-1 (9-73)

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INTRODUCTION

The Air Quality Act of 1967 required HEW to investigate and report on aircraft engine emissions and their impact on air quality. HEW sponsored a study and reported its findings to Congress as directed. As a result of the findings, HEW and DOT negotiated a voluntary smoke retrofit agreement with 31 airlines. The 1970 Amendments to the Clean Air Act required another investigation of aircraft emissions and also granted EPA regulatory authority to set standards as needed to protect the public health or welfare. EPA studied the problem and developed standards which were promulgated in final form in July 1973. These standards contained requirements applicable in 1979 for newly manufactured turbine and piston engines, with more stringent requirements applicable in 1981 for newly certified large turbine engines.

Since 1973, EPA has monitored the progress of the technology needed to meet these existing standards and reviewed the impact of various classes of aircraft on ambient air quality. As a result, there is now in draft form an NPRM to amend the existing standards. As proposed in this draft, emission standards for engines other than commercial turbine engines would be withdrawn. Standards for gaseous emissions from commercial turbine engines would be relaxed and delayed, as required by the status of the control technology and by lead time considerations. In addition, an earlier proposal for a gaseous emission retrofit program has been revised and is included in the draft NPRM. This program would require retrofit of HC and CO controls on all in-use commercial turbine engines with rated thrust greater than 12,000 pounds. This cutoff point includes the majority of the commercial turbine engine population.

During the preparation of the draft NPRM, commenters, particularly FAA, questioned the air quality justifications for the standard for NOx emissions from newly manufactured engines and for the HC and CO retrofit program. In addition, EPA may soon set an ambient air quality standard for short-term concentrations of NO_2, a possibility that generally was not considered in the past studies which supported the amendments now in draft form. FAA has announced that it will conduct a new study of the air quality impact, to be completed in 1979. EPA will participate in this study.

Previous air quality studies, of which there have been many, have not been so conclusive as to resolve all uncertainties about the impact of commercial aircraft on air quality. It is therefore possible that present uncertainties will be resolved, or at least modified, by the new FAA study in a way which contradicts the conclusions which justified the amendments contained in the draft NPRM. If this occurs, EPA will of course consider further modifications to the standards in light of the new information.

This report is partial documentation of EPA's review of the past air quality studies. Reference 1 recently reviewed the NO_2 findings from past studies. This report reviews the HC, CO, and NO_2 air quality justifications for the commercial aircraft emission standards contained in the NPRM. It discusses which points can be considered settled and which remain unsettled. And it considers what questions the new air quality study needs to address in order to help clarify the unsettled points.

REVIEW OF PAST AIRPORT AIR QUALITY STUDIES

Chronology

Several agencies and groups concerned with aircraft emissions have conducted a number of studies addressing the impact of aviation on air quality. The information gathered or calculated by these results has included emission inventories for airport-related emission sources, air quality monitoring data on pollutant concentrations, and predictions for pollutant concentrations based on mathematical dispersion models. Five of the nation's major commercial airports (JFK, Washington National, Atlanta International, O'Hare, and L.A. International) and several smaller airports have received some degree of attention from one or more of the past studies.

The earliest study[2] was in response to the requirements of the 1967 Air Quality Act. The contractor for the study attempted to compile emission inventories for JFK, Washington National and L.A. International airports, and for all FAA controlled terminals combined, for the year 1967. Lack of good data on engine emission factors and on operational characteristics at each airport resulted in wide uncertainty ranges around the inventory estimates. The study also included a few very simple dispersion calculations.

After enactment of the 1970 Amendments to the Clean Air Act, EPA sponsored two further studies. The Los Angeles County Air Pollution Control District (APCD) compiled a detailed, current emission inventory for all sources at L.A. International and monitored concentrations of CO and particulates in and around the airport for six months.[3]

Northern Research and Engineering[4] (NREC) developed a mathematical dispersion model and compiled emission inventories for 1970, 1975, and 1980 for Los Angeles International, Washington National, JFK, and O'Hare airports and their surrounding regions. The dispersion model was used to predict concentrations of pollutants in and around all four airports for 1970 and for L.A. International for 1975 and 1980. One specific goal of the modeling was to identify the contribution of aircraft to local air quality problems, a task that could not have been accomplished by air quality monitoring or emission inventorying alone.

In 1972 EPA published its own study[5] on aircraft emissions, dealing with both their impact on air quality and the technology for their control. The air quality section of the report was based predominately on the NREC and L.A. Air Pollution Control District studies. EPA did revise the NREC results in several places to account for more up-to-date emission factors than those used by NREC. It also added some additional calculations combining the results of the two studies. EPA compared aircraft emission control to other control strategies which states were considering at the time.

In its report, NREC had compared its dispersion predictions and emission inventories to those of the APCD. The comparison showed wide disparities between the two studies. As the model was used further it became evident that it was capable of order-of-magnitude underpredictions of pollutant concentrations. EPA contracted Geomet, Inc. to verify the NREC model against monitoring data from Washington National.[7] Geomet did not test the original NREC model against the monitoring data it collected at National. Instead, Geomet made some immediate, minor improvements to the NREC model, tested it, and found it underpredicting but by less than had been reported by others. It then made further, major improvements in the model and concluded that this version (renamed the Geomet model) performed acceptably. Geomet's opinion was later challenged by researchers at Argonne National Laboratory.[8] The Geomet study only developed the new version of the airport model. It did not answer the same questions that NREC had tried to answer with its model. Geomet has since applied its model to smaller airports in connection with the preparation of environmental impact statements.[9,10,11]

Another pair of airport air quality models, similar in purpose to the NREC/Geomet models, was developed by Argonne National Laboratory. The Airport Vicinity Air Pollution (AVAP) model was developed for the FAA. Argonne also developed the Air Quality Assessment Model (AQAM) for the U.S. Air Force. The analytical methods used in AVAP and AQAM are similar and the two models have given similar results when applied to the same airport.[7] The two models differ only in that one is tailored to operating conditions at commercial airports, the other to those at military airports.

The AVAP model was developed and validated using O'Hare and Orange County airports as example cases.[12] The O'Hare version of the model was not used to analyze the contribution to air quality deterioration from commercial aircraft. The purpose of this particular application was model development only.

Argonne has since addressed the question of air quality impact from commercial aircraft in two studies, both using AVAP. FAA contracted with Argonne to use AVAP to study the issue of air quality at Washington National.[13] The results of the study were published in July 1974. The National version of AVAP was validated using data from twenty days of CO monitoring during 1972.

EPA also contracted with Argonne for an air quality study using the AVAP model.[14] This study, published in January of 1975, used Atlanta's Hartsville International Airport as a setting for a comparison of several alternate strategies for reducing airport emissions. The study was not specifically addressed to the question of the impact of commercial aircraft emissions on air quality, but since a reduction in engine emissions was one of the strategies considered in the study it is possible to use the study's results to help answer that question.

The Air Force and the Navy have also used dispersion models to assess air quality problems around their air bases. The Air Force made a ten-base study using Argonne's AQAM model. The Navy used a modified version of AQAM in a study of NAS Miramar, near San Diego.

During May and June of 1976, EPA monitored the air quality in Mountain View, Georgia.[17] This small town is very near the Atlanta Airport.

The dispersion models used in all of the air quality studies did not account for chemical and photochemical reactions. Systems Applications Incorporated has attempted to better account for the reactive steps connecting aircraft NOx and HC emissions to ambient concentrations of oxidants.[18]

While these air quality studies were in progress, EPA continued to monitor the development of the technology needed for compliance. As part of this work, EPA has compiled up-to-date aircraft emission inventories for L.A. International, JFK, and O'Hare airports for the years 1972, 1975, 1980 and 1985.[19]

Model Validity

As a result of the past airport air quality studies, several estimates of the impact commercial aircraft have on pollutant concentrations near five major airports are now available. Each of these estimates has been made with one of three dispersion models: NREC, Geomet, or AVAP. A discussion of the validity of these three models is necessary in order to interpret the estimates that will be reviewed shortly.

From a regulatory viewpoint it is desirable to know (1) the spacial and temporal distribution of pollutant concentrations attributable to commercial aircraft alone and (2) the concentrations due to other emission sources. If aircraft emissions alone are enough to cause violations of the national ambient air standards it is necessary to control them in order to achieve the standards. If aircraft emissions do not by themselves cause violations but contribute to them, it may still be that aircraft emission standards will be a desirable element in an overall control strategy. The first question is asked first, since it may eliminate the need to ask the second.

There are three steps in predicting the ambient concentrations of pollutants attributable to commercial aircraft, each with pitfalls. The first is to take inventory accurately: the spatial and temporal distribution of emissions from aircraft must be modeled. Second, the dispersion of these pollutants over the airport and surroundings must be modeled. Third, reactions involving the pollutants while they disperse must be modeled if they occur.

As mentioned earlier, none of the dispersion models used to date have attempted the third of these steps. For the reactive pollutants, NOx (mostly NO when emitted) and HC, the models predict concentrations either as if no reactions were involved or as if the reactions were instantaneous.

There are two approaches to assessing the accuracy of the other two steps. Where possible, the emission inventories for the same airport can be compared between dispersion models and with inventories prepared independently, for example those of EPA[19] or the Los Angeles APCD.[3] Unfortunately, this is difficult to do precisely because the studies did not all cover the same airports, dates, and hours. The best comparison possible is in terms of annual emissions from all aircraft using the given airport. These numbers will include non-commercial aircraft but this is unavoidable since some studies did not separate the two types. Non-commercial aviation is generally minor at the airports under consideration.[20]

Figures 1 through 4 show the comparison for the four airports for which more than one estimate has been made (Atlanta is the exception). It should be remembered that three factors influence the positions of the curves: the numbers and types of aircraft and engines using an airport, the way they operate while there, e.g., taxi-idle time, and the emission factors for the engines. Obviously, differences in the way past studies have estimated these factors have resulted in significant differences in emission inventories. It is not immediately clear which estimate is correct in each case. However, the estimates from Reference 19 are based on the most recent, and presumably most accurate, emission factors; they may not be based on the best airport usage data. The emission factors used in Reference 4 are the oldest and least reliable. Reference 5, the EPA report, updated the inventory estimates in Reference 4 using newer data published by the Cornell Aeronautical Laboratory.[21] As can be seen in the figures, this updating resulted in inventory estimates closer to those in Reference 19, with the exception of JFK and L.A. where the improvement was mixed. The inventory estimates from References 12 and 13 were also based on the Cornell emission factors, as were the inventories for Atlanta (Reference 14, not shown in figures). Generally, the various predictions agree less for future years than for past years. The L.A. NOx projection for 1980 from the 1972 EPA report is the most notable example of this disagreement.

The second approach to assessing the accuracy of a dispersion model is to compare its predictions for pollutant concentrations with monitoring data. This serves as a check on the inventory and dispersion steps combined. Validation against monitoring data is only possible for total concentrations, and so a model must be capable of predicting concentrations from all important sources. However, while inventorying aircraft and other airport sources is relatively straightforward and much the same for any airport, inventorying emissions from airport emissions is more difficult and unique for each airport. Each of the airport models has tried to account for these environ sources.

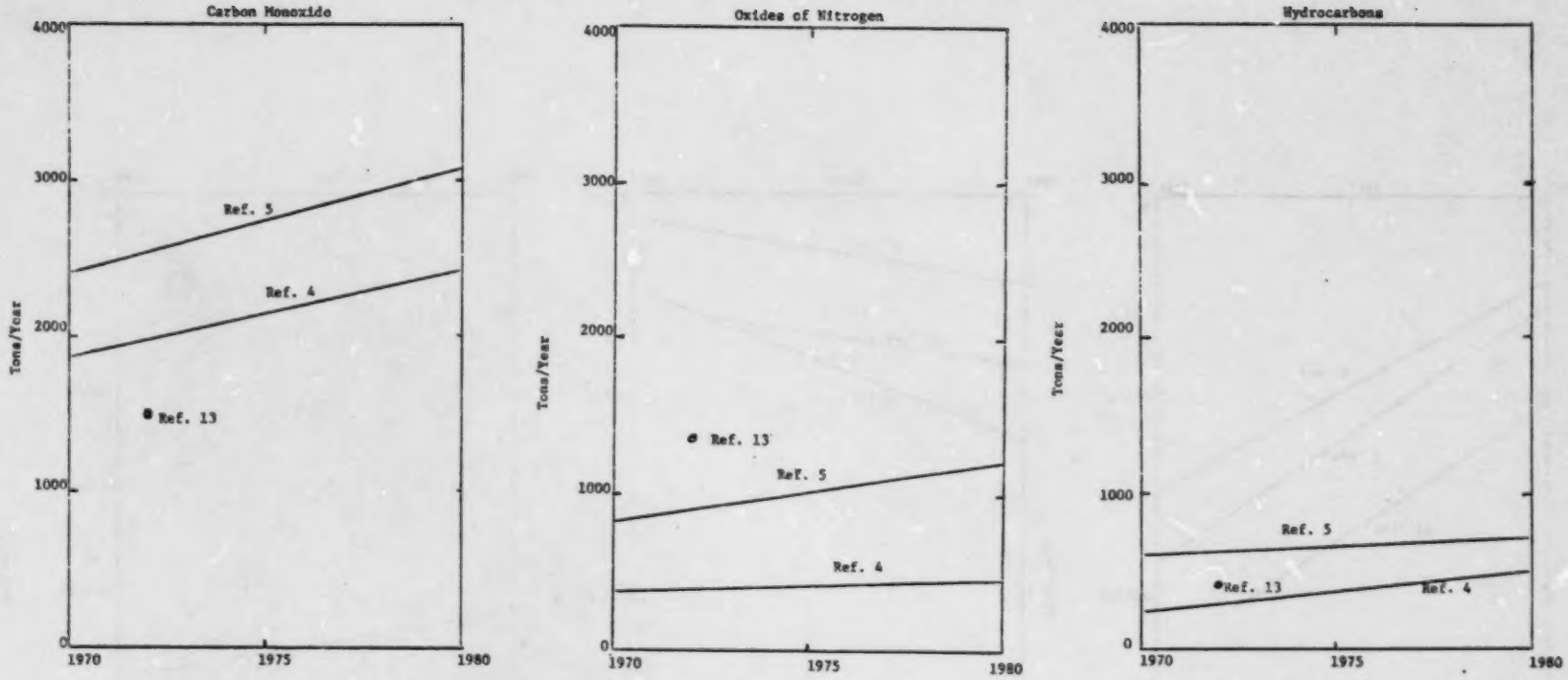

Figure 1. Comparison of Estimates of Aircraft Emissions at Washington National, 1970-1980

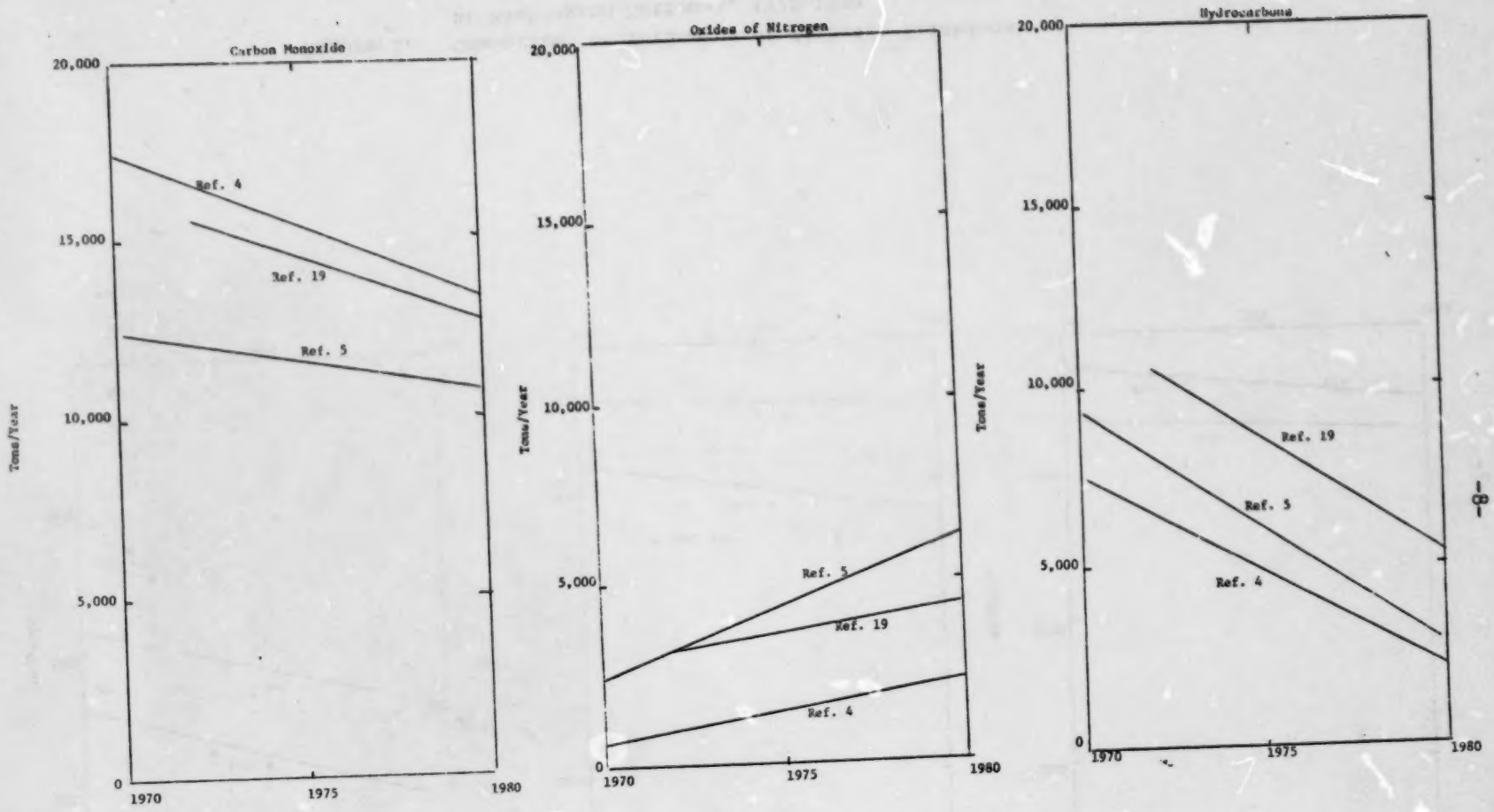

Figure 2. Comparison of Estimates of Aircraft Emissions at J.F.K., 1970-1980

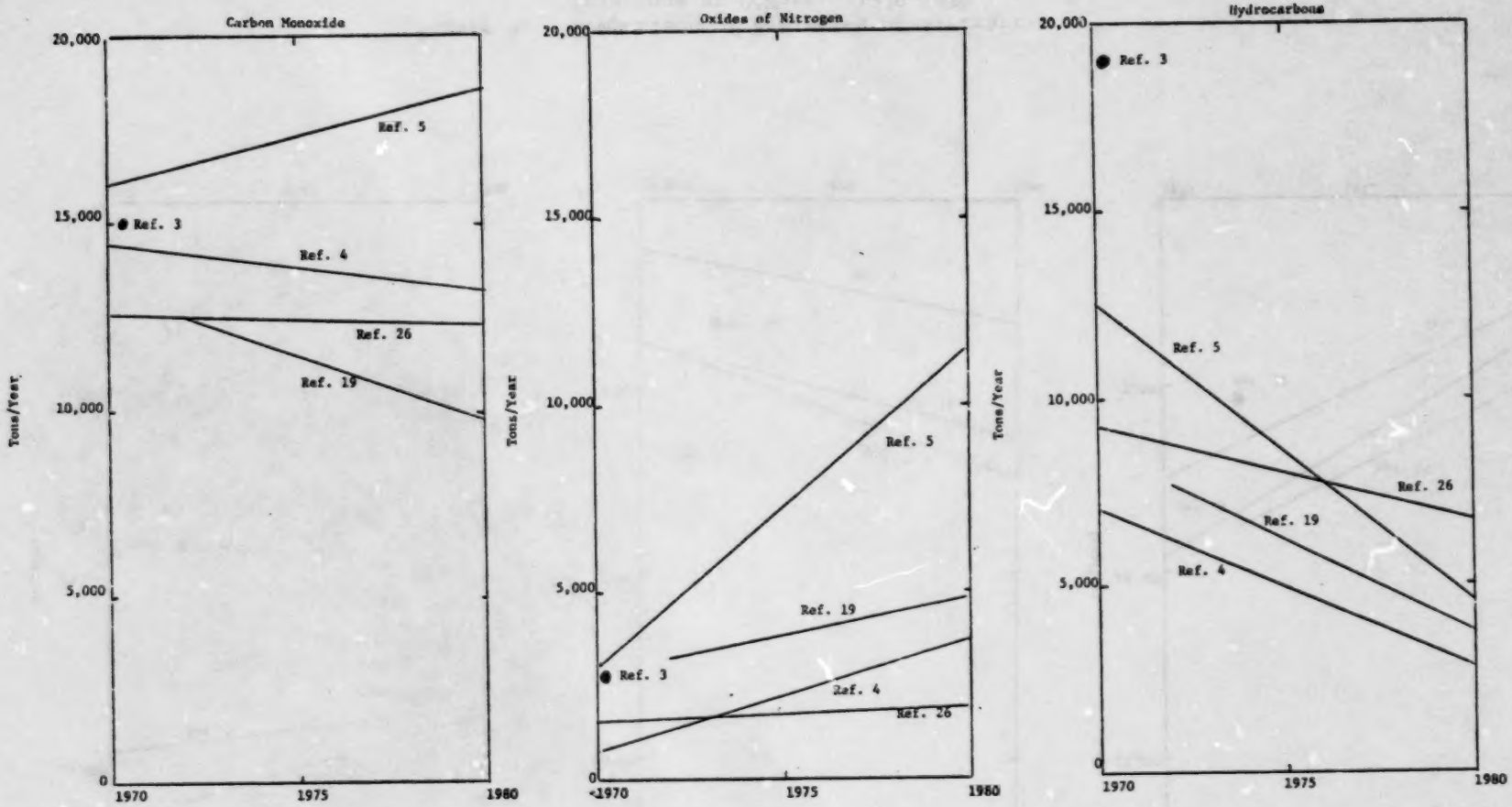

Figure 3. Comparison of Estimates of Aircraft Emissions at L.A. International, 1970-1980

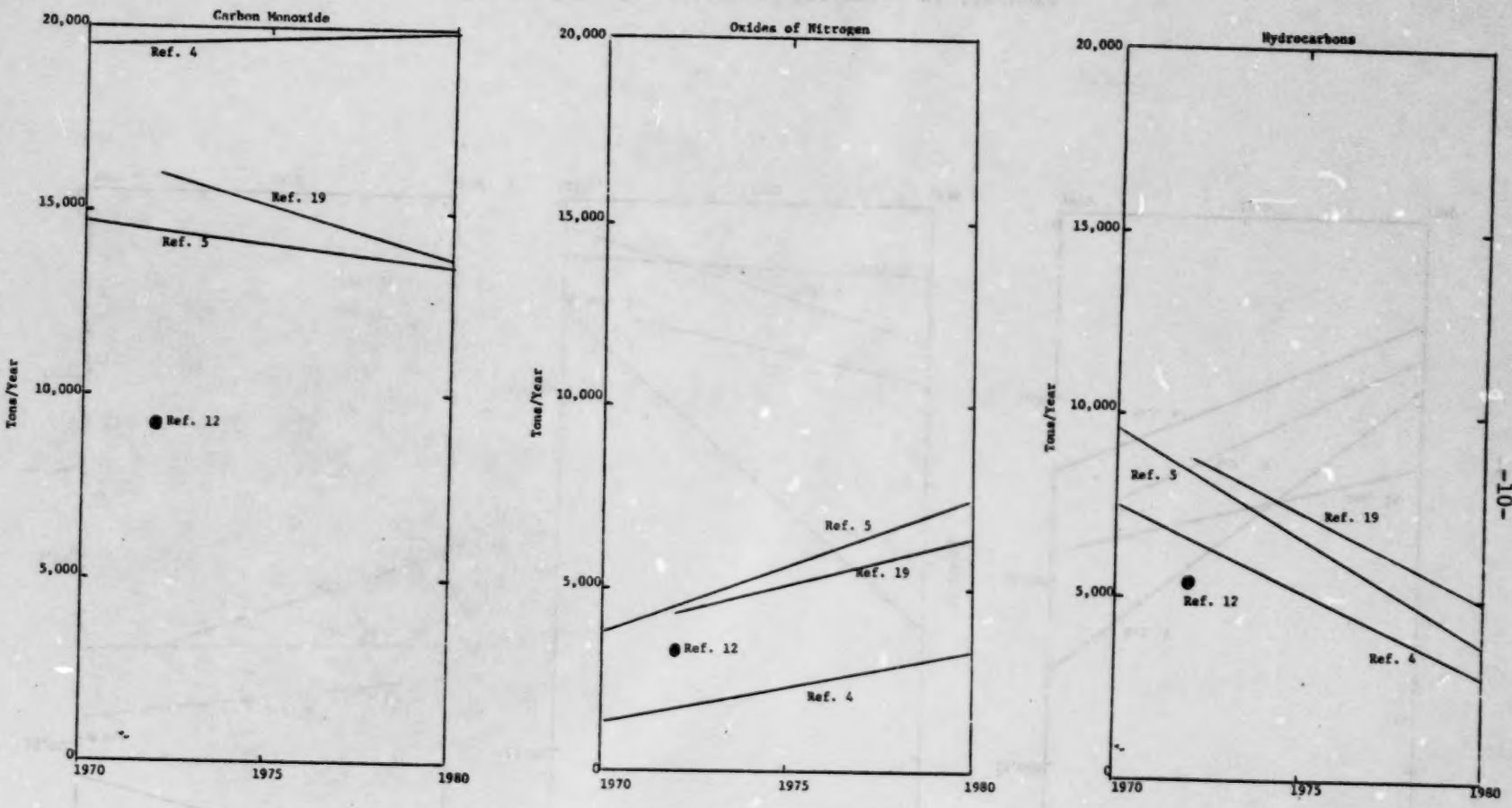

Figure 4. Comparison of Estimates of Aircraft Emissions at O'Hare. 1970-1980

The NREC model for L.A. International underpredicted HC and NOx emission inventories for the airport itself compared to those of the APCD. It agreed fairly well on the CO inventory, but still underpredicted CO concentrations by a factor of about 2.8. NREC attributed this to a poor model of environ CO sources. Later, Geomet decided that the dispersion algorithm of the NREC model was itself partly to blame and modified it in ways that gave consistently higher concentrations. This version of the NREC model still underpredicted when compared with monitoring data from Washington National. Geomet thought this was due to faulty inventories for both airport and environ sources and to the coarseness of NREC's source point model. Thus, the NREC model has been shown to be incapable of predicting total pollutant concentrations. What little evidence is available suggests that the model underpredicted concentrations due to aircraft sources, assuming its emission inventory was correct.

After Geomet made further changes to arrive at the Geomet model, it compared the frequency distribution of concentration levels predicted by the model to the distribution from monitoring data. The Geomet model did fairly well for the non-reactive pollutants except at the low frequency/high concentration end of the distribution - where violations of ambient standards would be expected. The Geomet model was later criticized for being unable to match measured concentrations on an hour-by-hour basis.

Argonne's AVAP model has been tested against monitoring data at O'Hare, Washington National, and Atlanta. The model was found to perform well enough in predicting total NOx concentrations at O'Hare, a case in which emissions from non-airport sources did not contribute much background noise. The model did somewhat less well for CO at National and Atlanta. For reactive pollutants and ones for which poorly modeled environ sources were important, the AVAP model has done poorly. Thus, there is evidence that suggests that the AVAP model can reasonably accurately predict concentrations of non-reactive pollutants from aircraft, and no specific evidence that it cannot.

None of the models account for obstructions to dispersion such as buildings, and should not be trusted to predict concentrations due to such obstructions. Further, comparisons of predicted NOx to measured NO_2 have usually shown overprediction, since some of the predicted NOx is NO.

Model and Monitoring Results

Table 1 lists the national ambient air quality standards for CO, NO_2, and HC. In addition, EPA may establish a short-term NO_2 standard in the near future. This standard, if established, might be in the range of 190 to 320 $\mu g/m^3$ hourly average NO_2, the range of current World Health Organization recommendations. The WHO recommendations are that the hourly average not be exceeded more than once per month.

Table 1 NATIONAL AMBIENT AIR QUALITY STANDARDS

Pollutant	Standard Description
Carbon monoxide (Primary and secondary standards are the same)	- 10 milligrams per cubic meter (9 ppm), maximum 8-hour concentration not to be exceeded more than once per year. - 40 milligrams per cubic meter (35 ppm), maximum 1-hour concentration not to be exceeded more than once per year.
Nitrogen dioxide (Primary and secondary standards are the same)	- 100 micrograms per cubic meter (0.05 ppm), annual arithmetic mean.
Hydrocarbons (non-methane) (Primary and secondary standards are the same)	- 160 micrograms per cubic meter (0.24 ppm), maximum 3-hour concentration (6-9 a.m.) not to be exceeded more than once per year. For use as a guide in devising implementation plans to meet the oxidant standards.
Particulate matter Primary standard	- 75 micrograms per cubic meter, annual geometric mean. - 260 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.
Secondary standard	- 60 micrograms per cubic meter, annual geometric mean, as a guide to be used in assessing implementation plans to achieve the 24-hour standard. - 150 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.
Sulfur dioxide Primary standard	- 80 micrograms per cubic meter, annual arithmetic mean. - 365 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.
Secondary standard	- 60 micrograms per cubic meter, annual arithmetic mean. - 260 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year. - 1300 micrograms per cubic meter, maximum 3-hour concentration not to be exceeded more than once per year.
Oxidant (Primary and secondary standards are the same)	- 160 micrograms per cubic meter, maximum 1-hour concentration, not to be exceeded more than once per year.

In the summary of results that follows, no mention of a study's results usually means the study did not yield any useful information on that topic.

Carbon Monoxide

The results of the CO monitoring at L.A. International by the APCD[3] are summarized in Table 2. The "satellite" locations in the table are passenger terminals completely surrounded by ramp areas. The ticketing building is adjacent to an access road and loading area. The table shows that the one-hour CO standard was exceeded repeatedly at two satellite terminals and the ticketing building. The monitored violations at the terminals were probably due to aircraft and ground service vehicles combined, judging from the locations. Access traffic was probably responsible for the violations at the ticket building. Figure 5 compares the frequency distribtuions of the CO measurements from two monitoring stations. Station 204 was west (generally upwind) of the airport; station 208 was at one of the passenger terminals. The figure indicates the frequency of the CO violations and the effect airport emissions had on raising CO concentrations above those in the upwind areas.

The NREC model[4] predicted that aircraft sources alone would cause CO levels above the standards at the ends of runways at all four airports and at a terminal at JFK. CO levels at most other points were quite low. NREC's CO inventory for aircraft sources at O'Hare was about 25% high compared to other estimates; its inventories for other airports were in general agreement with other estimates (see Figures 1-4).

The EPA report[5] summarized the CO results from the APCD and NREC studies. It also looked more closely at a specific monitoring site in L.A. where a residental area was close to and downwind of a runway. EPA noted that the APCD monitoring data had shown frequent violations of the CO standard at this site. It then used a rollback calculation to show that, if the present contribution by aircraft to measured CO levels at that site were more than 20%, there would still be CO violations at the site even after other CO sources were controlled. While the NREC model had not predicted any violations at the site because of its general tendency to underpredict, it did suggest that the percent contribution from aircraft was over 20%. No conclusion should be drawn without first remembering that the NREC model tended to overpredict the percent contribution from aircraft because it had much too low an inventory for non-aircraft sources.

While monitoring at Washington National, Geomet[7] recorded violations of both CO standards at a terminal and at a maintenance area and violations of the eight-hour standard at another runway and in the auto traffic and parking area. The summary of Geomet's monitoring is given in Table 3. The CO levels in the terminal and maintenance area reached twice the allowed levels at their maximum. Although Geomet's model was capable of predicting the aircraft contributions to pollutant concentrations, Geomet did not report them. Geomet made a general comment that "aircraft

Table 2. Results of CO Monitoring at L.A. International

STA. NO.	LOCATION		CARBON MONOXIDE One-Hour Avg. - ppm - --Range-- Min.	Max.	Arith. Mean
MAY (from 5/10/70)					
204	F.A.A. VOR Site West End	0[a]	1	19	3.0
209	Command Post, East End	0	1	21	3.4
201	Control Tower, Admin. Bldg.	0	1	21	4.8
203	Satellite 2	0	1	15	3.7
202	Satellite 2	I[a]	2	35	8.0
208	Satellite 7	0	2	22	5.3
207	Satellite 7	I	4	63	11.1
205	Ticketing Bldg., No. 7	0	-	-	-
206	Ticketing Bldg., No. 7	I	5	70	13.6
APCD MONITORING STATIONS					
76	Southwest Coastal (Lennox)	0	2	35	6.2
1	Central (Downtown L.A.)	0	1	35	5.5
JUNE					
204	F.A.A. VOR Site West End	0	1	6	2.2
209	Command Post, East End	0	1	18	3.2
201	Control Tower, Admin. Bldg.	0	2	12	4.6
203	Satellite 2	0	1	26	6.2
202	Satellite 2	I	2	79	9.3
208	Satellite 7	0	1	18	4.8
207	Satellite 7	I	2	90	11.3
205	Ticketing Bldg., No. 7	0	-	-	-
206	Ticketing Bldg., No. 7	I	2	66	13.3
APCD MONITORING STATIONS					
76	Southwest Coastal (Lennox)	0	2	18	6.2
1	Central (Downtown L.A.)	0	1	24	5.0
JULY					
204	F.A.A. VOR Site West End	0[a]	1	5	1.7
209	Command Post, East End	0	1	8	3.3
201	Control Tower, Admin. Bldg.	0	1	10	4.4
203	Satellite 2	0	1	20	4.6
202	Satellite 2	I[a]	2	110	9.8
208	Satellite 7	0	1	24	5.1
207	Satellite 7	I	1	75	9.8
205	Ticketing Bldg., No. 7	0	-	-	-
206	Ticketing Bldg., No. 7	1	3	51	13.1
APCD MONITORING STATIONS					
76	Southwest Coastal (Lennox)	0	2	20	6.1
1	Central (Downtown L.A.)	0	2	25	5.0
AUGUST					
204	F.A.A. VOR Site West End	0[a]	1	12	2.2
209	Command Post, East End	0	1	14	3.6
201	Control Tower, Admin. Bldg.	0	1	14	5.1
203	Satellite 2	0	1	29	5.5
202	Satellite 2	I[a]	1	141	10.9
208	Satellite 7	0	1	28	5.6
207	Satellite 7	I	3	74	10.1
205	Ticketing Bldg., No. 7	0	-	-	-
206	Ticketing Bldg., No. 7	I	3	132	15.8
APCD MONITORING STATIONS					
76	Southwest Coastal (Lennox)	0	2	23	6.6
1	Central (Downtown L.A.)	0	1	27	4.0
SEPTEMBER					
204	F.A.A. VOR Site West End	0	1	18	3.9
209	Command Post, East End	0	1	31	5.0
201	Control Tower, Admin. Bldg.	0	2	27	6.4
203	Satellite 2	0	2	46	7.2
202	Satellite 2	I	2	79	10.3
208	Satellite 7	0	2	27	7.0
207	Satellite 7	I	3	39	8.2
205	Ticketing Bldg., No. 7	0	-	-	-
206	Ticketing Bldg., No. 7	I	3	86	12.6
APCD MONITORING STATIONS					
76	Southwest Coastal (Lennox)	0	1	41	6.0
1	Central (Downtown L.A.)	0	1	24	4.6
October					
204	F.A.A. VOR Site West End	0[a]	1	23	4.9
209	Command Post, East End	0	1	27	5.9
201	Control Tower, Admin. Bldg.[b]	0	3	24	7.1
203	Satellite 2	0	2	40	7.4
202	Satellite 2	I[a]	3	68	10.4
208	Satellite 7	0	1	37	7.7
207	Satellite 7	I	3	35	8.3
205	Ticketing Bldg., No. 7[b]	0	2	51	18.5
206	Ticketing Bldg., No. 7	I	4	92	15.0
APCD MONITORING STATIONS					
76	Southwest Coastal (Lennox)	0	1	34	6.0
1	Central (Downtown L.A.)	0	1	30	6.0

(a) "0"--Outside; "I"--Inside.

(a) "0"--Outside; "I"--Inside.

Figure 5

FREQUENCY DISTRIBUTION, CARBON MONOXIDE, Hourly Averages

L.A. International Airport
(Source: Reference 3)

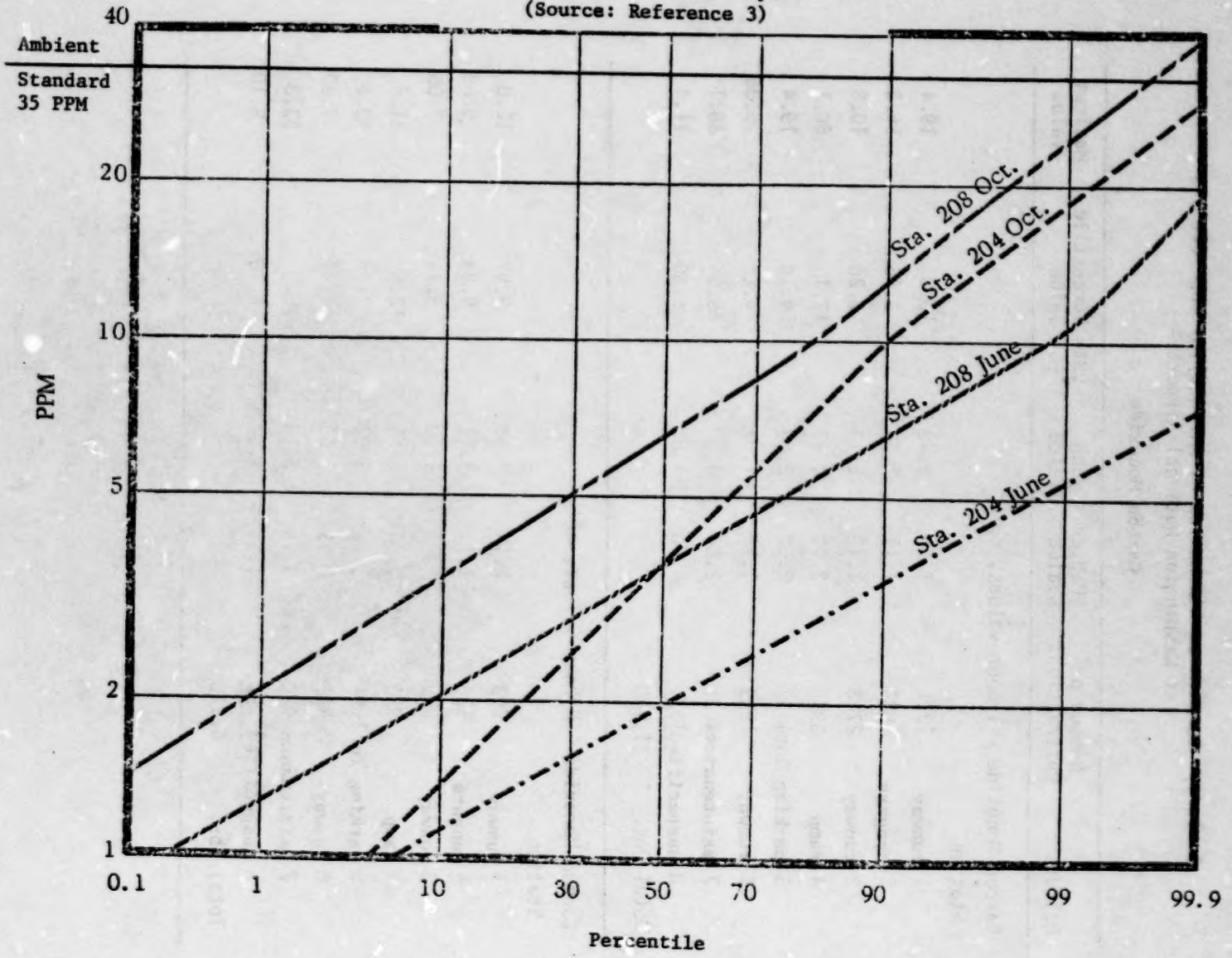

Table 3. Summary of Six Months of Air Quality Observations at Washington National Airport -

Carbon Monoxide

Pollutant	Number of Observations	Median Value	Mean Value	98th Percentile Value	Maximum Value
Carbon Monoxide - 1-hour values, mg/m^3					
Station					
1 **runway**	1321	1.70	2.48	10.0	19.4
2 **hangars**	1880	1.11	1.52	9.46	16.3
3 **runway**	2713	1.42	2.10	6.26	10.8
4 **ramp**	3975	3.40	4.43	17.1	60.1
5 **parking lot**	4137	2.50	2.99	9.10	19.4
6 **runway**	1599	1.28	1.52	4.86	9.35
7 **maintenance**	4061	2.80	4.97	69.5	88.1
8 **unspecified**	1574	1.70	1.84	6.80	11.4
Total Obs.	21,260				
Carbon Monoxide - 8-hour values, mg/m^3					
Station					
1 **runway**	293	2.14	2.59	9.97	12.0
2 **hangars**	428	1.12	1.52	9.33	9.63
3 **runway**	619	1.45	2.10	5.74	7.06
4 **ramp**	923	3.84	4.50	12.8	21.6
5 **parking lot**	1004	2.66	3.02	7.76	13.6
6 **runway**	381	1.33	1.53	4.44	7.29
7 **maintenance**	920	3.16	5.18	70.0	83.3
8 **unspecified**	352	1.64	1.87	6.10	8.10
Total Obs.	4,920				

and airport emissions represent, for Washington National Airport, only a very small fraction (of the order of a few percent) of the total pollution concentration burden, except on few occasions." The locations of the monitored violations seem to indicate that aircraft sources were important in at least some of the areas with monitored violations, however.

Argonne did not monitor CO concentrations in the course of its model development work at O'Hare. It only predicted CO concentrations for the few cases for which it also compared NOx predictions and measurements. The highest of these CO predictions was 8.5 $\mu g/m^3$ at the terminal area, below either CO standard. Argonne did not report what fraction of this was attributable to aircraft. It should be noted that the Argonne predictions did not account for the effect of obstructions to dispersion. Nor did the Argonne modelers select and make predictions for worst case conditions. It is thus possible that CO violations do occur at O'Hare.

Argonne both monitored and predicted CO levels as part of its study of Washington National.[13] Argonne's measurements did not cover as extended a period as did the Geomet measurements. Of the data it did take, Argonne reported only that for open areas near runways. Data from near the terminal building were rejected on the grounds that they could not be used in a validation test of a model which assumed no obstructions were present. In its monitoring near the runways, Argonne did not observe any CO violations even though it used sites similar to those where Geomet had measured violations.

Argonne's model did not predict CO violations at the auto parking area and terminal area, two sites where Geomet had actually observed violations. Argonne did predict that aircraft emissions alone would cause violations of both CO standards at points near the end of runways, under conditions ranging from average to worst-case. High levels due to all airport sources were more extensive. If the worst conditions occurred for eight hours at one time, the total CO level would exceed the standard over portions of the airport and some areas adjacent to it.

The study of the Atlanta airport by Argonne for EPA[14] did not observe any violations of the CO standards in its monitoring data and did not predict any violations, even under worst-case conditions. Although Atlanta ranks as a major airport, its CO inventory for aircraft sources is only about a third of that at L.A. International, JFK, or O'Hare. Atlanta's CO inventory is about twice that of National's, but is spread over a larger land area. These may be reasons why no violations were observed or predicted at Atlanta.

The Atlanta study does provide some information that is useful in interpreting violations at other airports, however. Figures 6a and 6b give an indication of the spatial distribution of CO levels due to aircraft. Figure 6a is a baseline that includes both aircraft and other

sources. Figure 6b represents the same conditions but with a 62% reduction in aircraft CO emissions. A comparison of the two figures shows that aircraft emissions predominate in areas slightly downwind of runways. CO concentrations outside the airport boundary are hardly affected by the large reduction in aircraft emissions. Although the figures do not show it clearly, CO levels at the ramp area during the summer decreased 40% with the 62% decrease in aircraft emissions, indicating that about 65% of the level in that area is due to aircraft, under summer wind conditions. Figures 7a and 7b show that the CO level due to the airport as a whole drops off very rapidly with distance from the airport. During summer the CO level from airport sources drops by a factor of five in the first two kilometers past the airport boundary; in the fall the decrease is slower but still fast. This suggests that at airports with CO problems attributable to aircraft, the problems will be localized.

The Geomet study of the Salt Lake City Airport[9] predicted that, in an airport with approximately one-tenth the aircraft CO emissions as those of the largest commercial airports, the only violation due to aircraft CO emissions was near the end of a runway. On an annual basis, CO levels from airport sources at points outside the airport boundaries were predicted to be at most a few percent of the eight-hour standard. The Salt Lake City model did not have enough resolution to predict concentrations within the airport itself, except for the runway site already mentioned.

The air bases studied in the Air Force project[15] were all small in comparison to the large commercial airports. Their CO emissions averaged about one-eighth those of O'Hare, for example. The report from the study was mainly concerned with the effects of the air bases on areas a few kilometers and more away. At five kilometers, annual average CO_3 levels attributable to military aircraft were no higher than 40 $\mu g/m^3$, i.e., less than a percent of the eight-hour CO standard.

In summary: Violations of CO standards have been observed at L.A. International and Washington National. These violations have occurred in areas that suggest aircraft emissions were important contributors. Violations due to aircraft alone have been predicted at these two airports and at O'Hare and JFK in addition. Observed and predicted violations have been limited to areas near the ends of runways and at terminal ramp areas. Aircraft contribute to violations beyond the airport boundaries in some cases, but in general the CO levels due to aircraft drop rapidly away from congested areas on the airport.

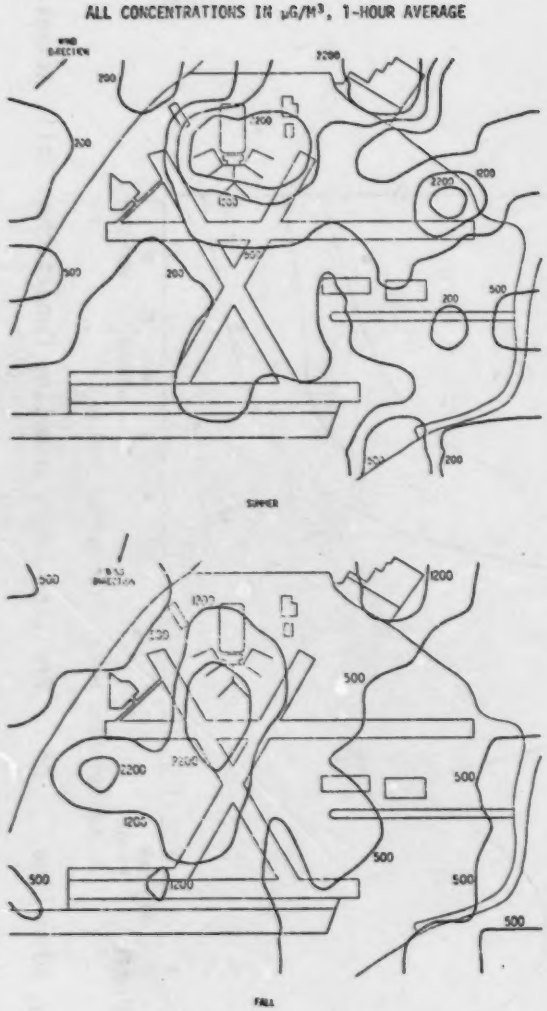

Figure 6a. Airport CO Concentrations for Baseline Conditions, Atlanta

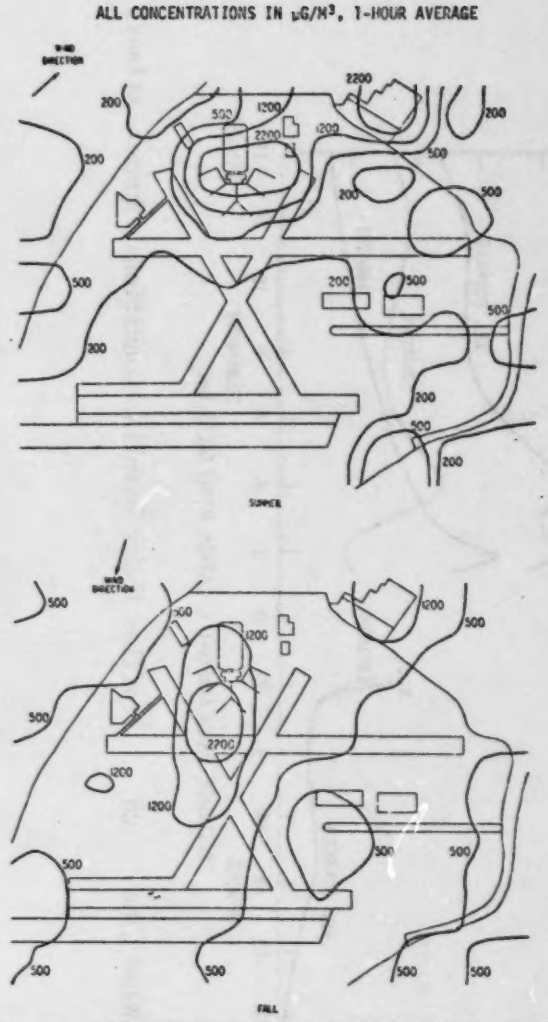

Figure 6b. Airport CO Concentrations for Engine Emission Standards Atlanta

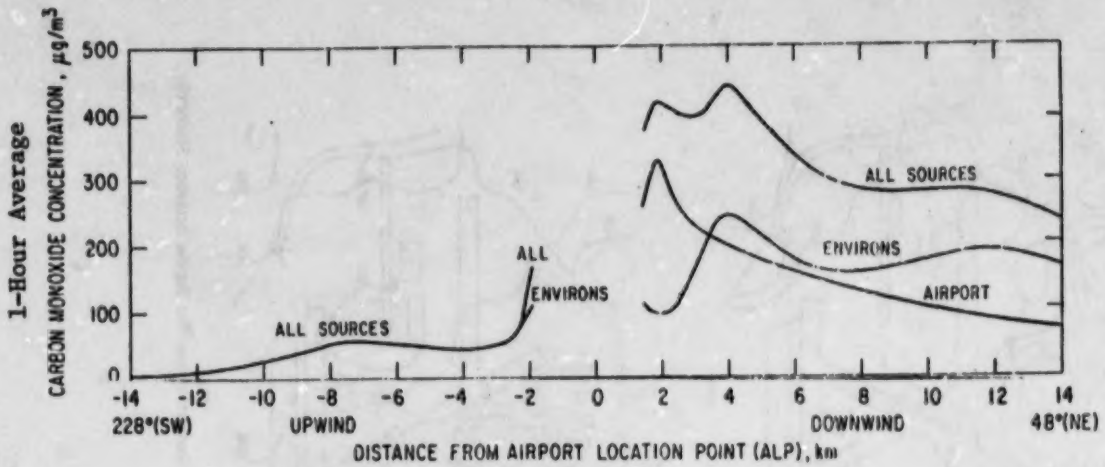

Fig. 7a. Wind Line CO Profiles Under Baseline Conditions, Summer, Atlanta

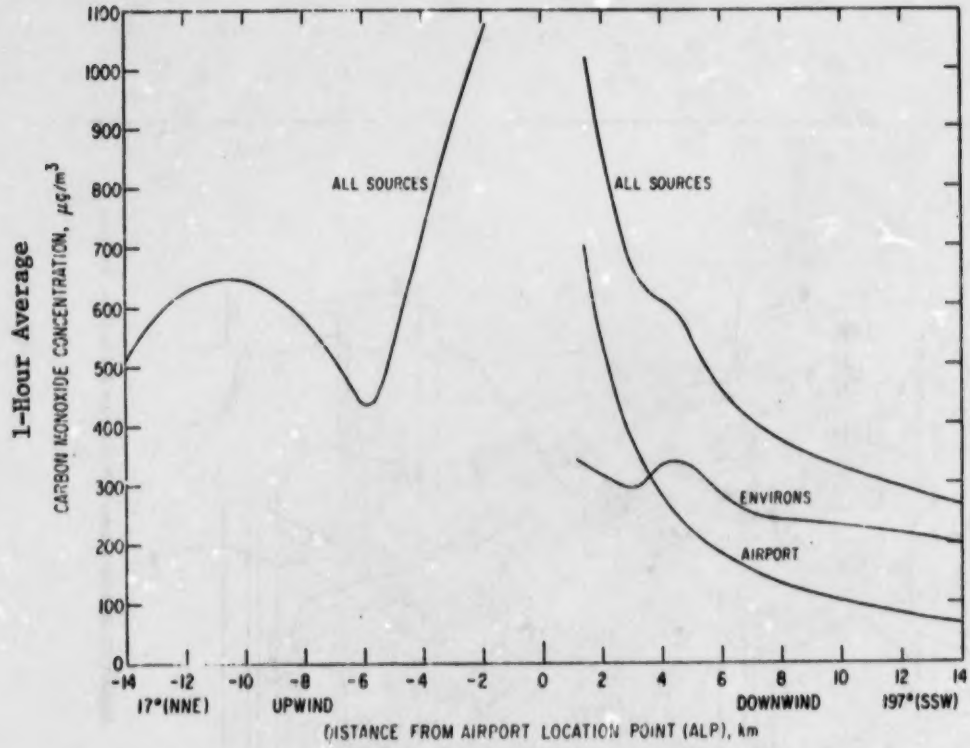

Fig. 7b. Wind Line CO Profiles Under Baseline Conditions, Fall, Atlanta

Hydrocarbons*

NREC[4] predicted that HC concentrations attributable to aircraft alone in the 6 am to 9 am period were above the national standard at points on each of the four airports modeled. At Washington National, the exceedances were by about a factor of three and limited to the areas around the end of runways. At JFK, they were very much higher, up to a factor of 40, and occured at terminals, runways, boundaries, and areas as much as 5 kilometers downwind. L.A. and O'Hare were in between these two extremes. For all four airports, other sources contribute towards large concentrations also, so that predicted violations from all sources covered most of the airport.

EPA[5] revised the NREC estimates and constructed HC isopleths for L.A., Figures 8a and 8b. EPA's 1970 HC inventory was high by about 30% while the 1980 inventory was close to the most recent estimate (see Figure 3). In both cases, the area experiencing violations from aircraft sources alone is predicted to extend well into the adjoining residential community. As mentioned earlier, HC is a reactive pollutant and is not harmful until it has reacted with NO_2 and light to form oxidants. EPA made a simple dispersion calculation to determine whether the HC would react before dispersing to such low levels that the product oxidants would not be of concern. The results are shown in Figure 9. The curves are drawn for 1980 and assume that non-aircraft HC sources have been controlled. The wind velocity is about 5 km/hr. With an assumed reaction time of 3 hours, the figure shows that aircraft sources alone would produce oxidant concentrations below, but close to, the ambient standard. With the higher HC emissions of 1970, the oxidant standard would have been found to be violated by aircraft sources alone. As it is, even in 1980 aircraft emissions contribute to a severe oxidant problem downwind of the airport.

Geomet took HC measurements at three sites at Washington National.[7] The results are summarized in Table 4. The maximum values for the 6 am - 9am period are so high that even if aircraft contributed only a few percent their contribution would be enough to violate the HC standard. The median and mean HC values indicate that high HC is a very frequent problem at National.

Argonne reported[12] HC measurements at O'Hare up to 20 times the standard, during one-hour periods throughout the day. Levels well outside the airport were about 5 to 10 times the standard. At O'Hare, aircraft accounted for 70% of airport HC emissions, so a very substantial part of the higher levels on the airport were due to aircraft.

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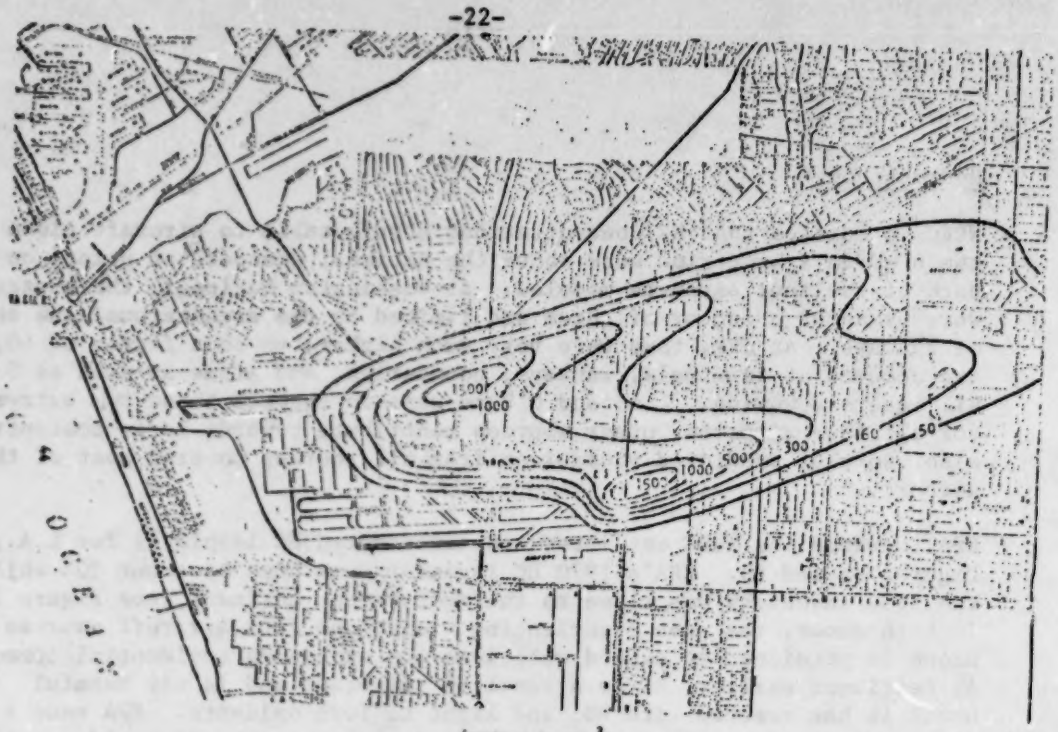
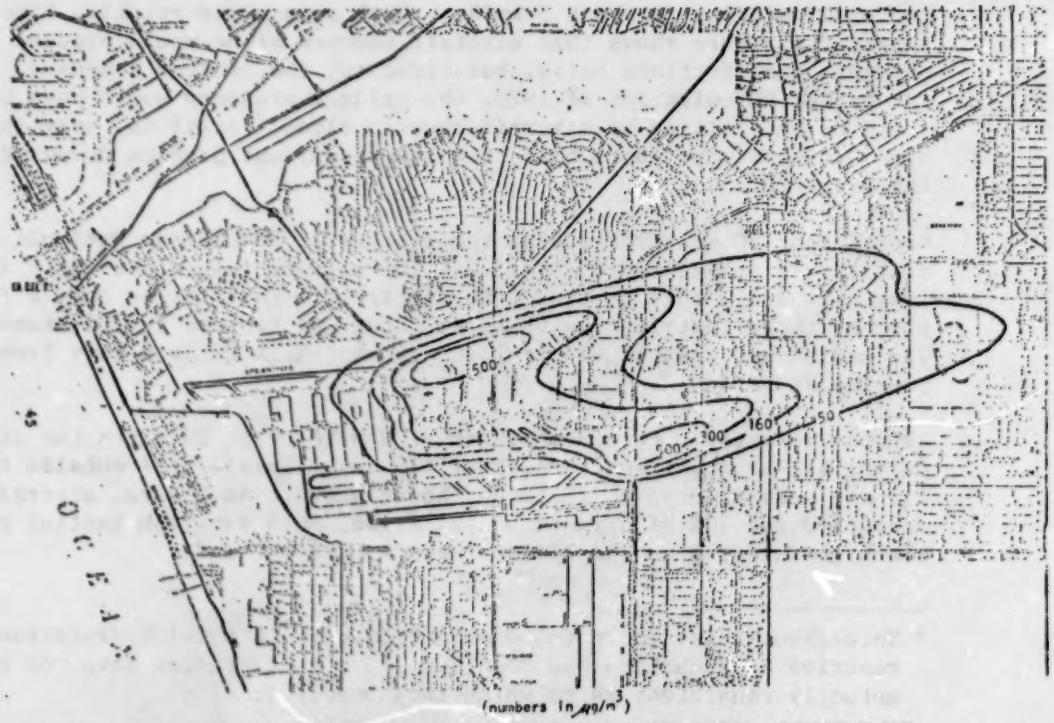
* Throughout this report the distinction between total hydrocarbons and reactive hydrocarbons has been ignored. Past studies have not been mutually consistent as to which they reported.



(numbers in $\mu g/m^3$)

Figure 8a. HYDROCARBON ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES
3-Hr Average for 1970 (6 - 9 AM)



(numbers in $\mu g/m^3$)

Figure 8b. HYDROCARBON ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES
3-Hr Average for 1980 (6 - 9 AM)

Figure 9

CALCULATED NON-METHANE HYDROCARBON CONCENTRATIONS
DOWNWIND OF LOS ANGELES AIRPORT FOR 1980
WITH NON-AIRCRAFT SOURCES CONTROLLED

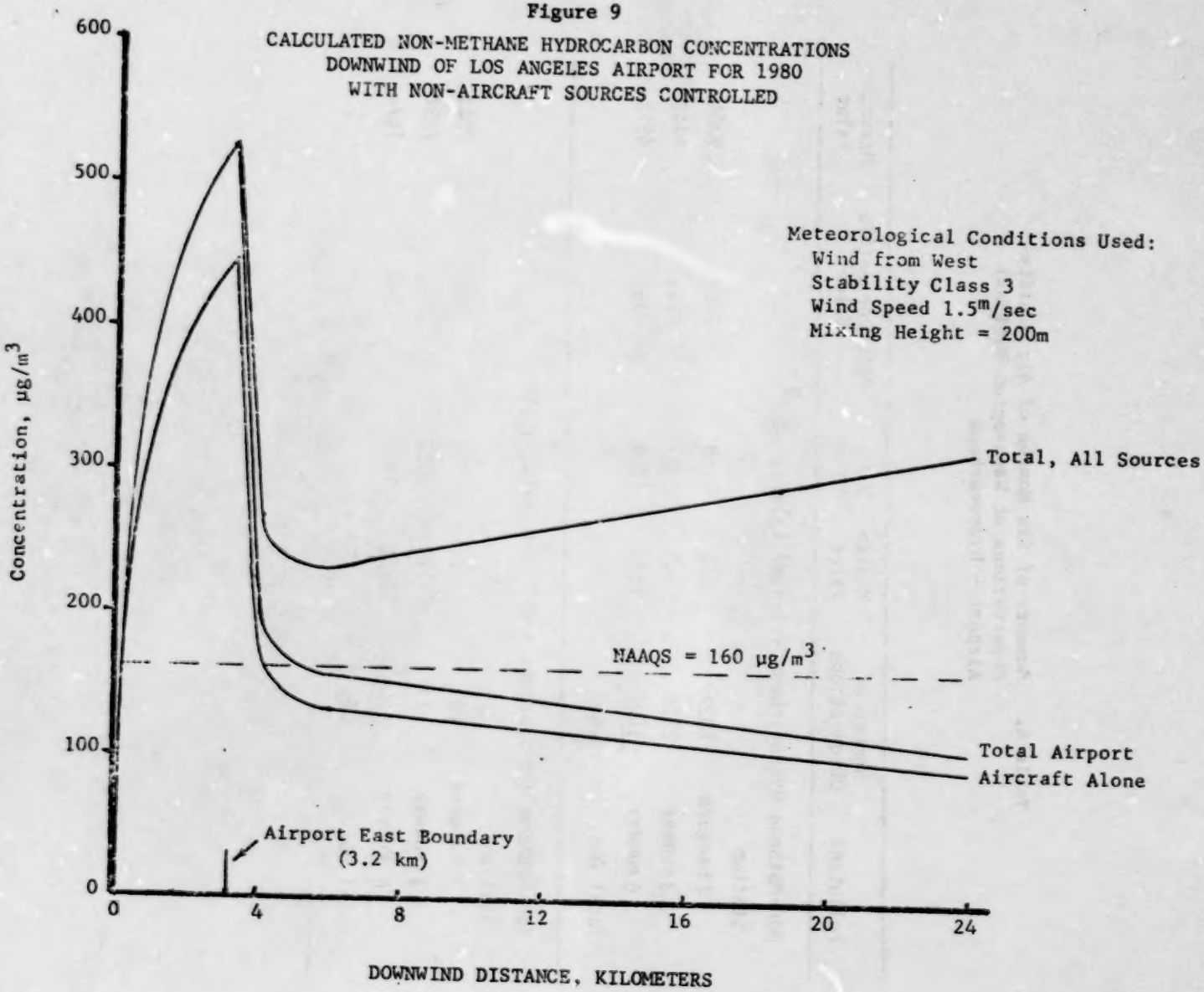


Table 4. Summary of Six Months of Air Quality Observations at Washington National Airport - Hydrocarbons

Pollutant	Number of Observations	Median Value	Mean Value	98th Percentile Value	Maximum Value
Non-Methane Hydrocarbons - 1-hour values, $\mu g/m^3$					
Station					
2 hangars	1922	655	1258	7788	9564
3 runway	2129	165	321	1828	4440
6 runway	1606	1238	1206	2461	4813
Total Obs.	5,657				
Non-Methane Hydrocarbons - 6-9 a.m. values, $\mu g/m^3$					
Station					
2 hangars	104	465	983	8677	9063
3 runway	73	171	320	2552	2934
6 runway	28	1229	1187	1974	1974
Total Obs.	205				

The predictions made by Argonne using the AVAP model at Washington National follow the pattern already described. With moderate to heavy aircraft activity and average to poor ventilation, air entering the airport boundary has HC levels about 5 times the level of the standard. It picks-up more HC as it passes over the airport and leaves with 10 or more times the standard at the downwind boundary. Dilution occurs downwind of the airport, but the HC level is still above the standard a mile away, the limit of the model's range. On the airport itself, both runways and terminals have high concentrations due to aircraft.

The Atlanta study again provided the most easily visualized results. All the HC results for Atlanta are based on model predictions. There were no HC measurements made. Figures 10a and 10b are taken from Reference 14 and are similar to Figures 6a and 6b which have already been explained. Aircraft HC emissions are 70% lower in Figure 10b than in 10a. Aircraft HC emissions at Atlanta are about one-third those at the largest commercial airports. Under baseline conditions, Figure 10a, HC concentrations exceed the 160 $\mu g/m^3$ level on the runways and terminal area, and in the parking areas. When aircraft HC emissions are reduced 70%, the changes in concentration levels indicate that aircraft alone were causing in excess of 160 $\mu g/m^3$ over both runways and terminal during part of the year. In summer, when the wind blows runway emissions into the terminal area, aircraft are responsible for a concentration of over 1000 $\mu g/m^3$ at the terminal (peak valves are not shown on the figures but are given in tables in the report). In the fall, this number is 238 $\mu g/m^3$.

Under worst case conditions, with poor ventilation and high airport activity, HC levels exceed the standard over the entire airport and into the surrounding areas, Figure 11. However, the Argonne report indicates that most of the HC levels in this case are attributable to emission sources upwind of the airport. The terminal area is an exception. There, aircraft are responsible for 450 $\mu g/m^3$ of the 1430 $\mu g/m^3$ total.

Figure 12 shows the impact of airport HC emissions on the area around the airport during normal baseline conditions. Only the town of Hapeville is predicted to experience HC violations due to airport sources. As aircraft account for only 70% of the total airport HC inventory, even Hapeville's predicted problem is not solely attributable to aircraft. However, under worst case conditions airport sources are responsible for HC violations up to 14 kilometers downwind, Figure 13. Even if the curve for airport sources in Figure 13 is moved downward 30% to account for the fact that not all airport sources are aircraft, violations due to aircraft alone extend about 7 kilometers downwind. The windspeed under the worst case conditions is 7 kilometers/hour, so airport HC emissions stay concentrated at high levels for two hours and aircraft emissions for one hour. This indicates that the possibility of oxidant formation cannot be ignored. And as long as other HC sources upwind of the airport remain uncontrolled, aircraft HC emissions are very definitely

ALL CONCENTRATIONS IN μG/M³, 1-HOUR AVERAGE

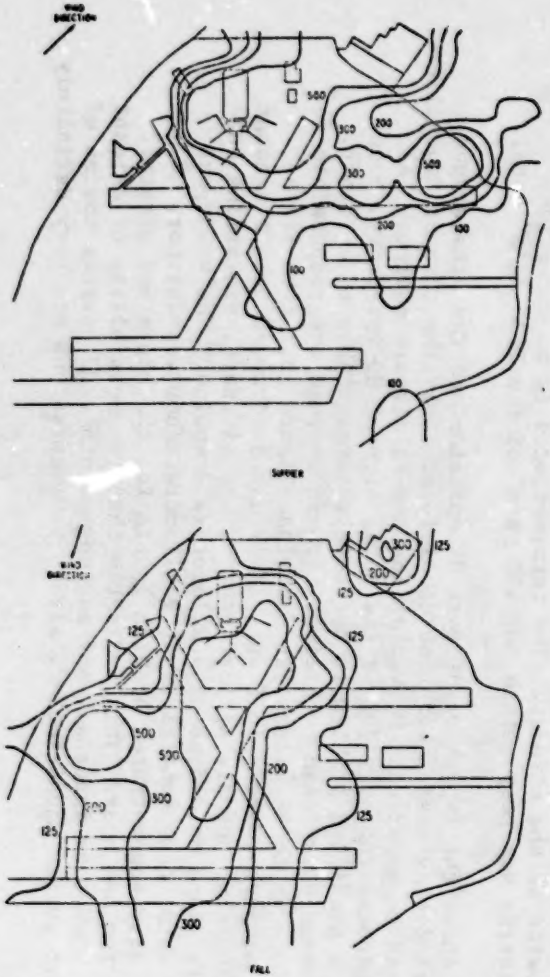


Fig. 10a. Airport HC Concentrations for Baseline Conditions - Atlanta

ALL CONCENTRATIONS IN μG/M³, 1-HOUR AVERAGE

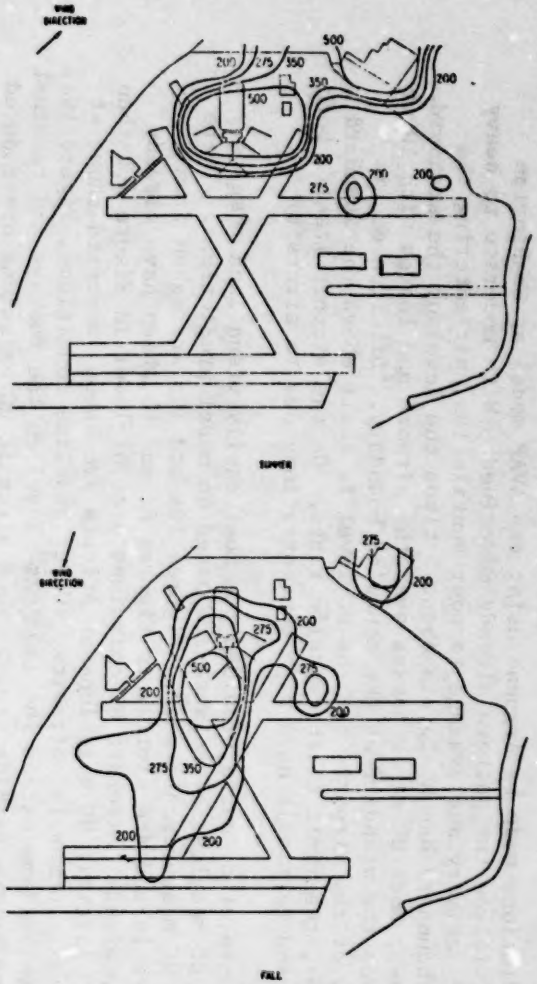


Fig. 10b. Airport HC Concentrations for Engine Emission Standards - Atlanta

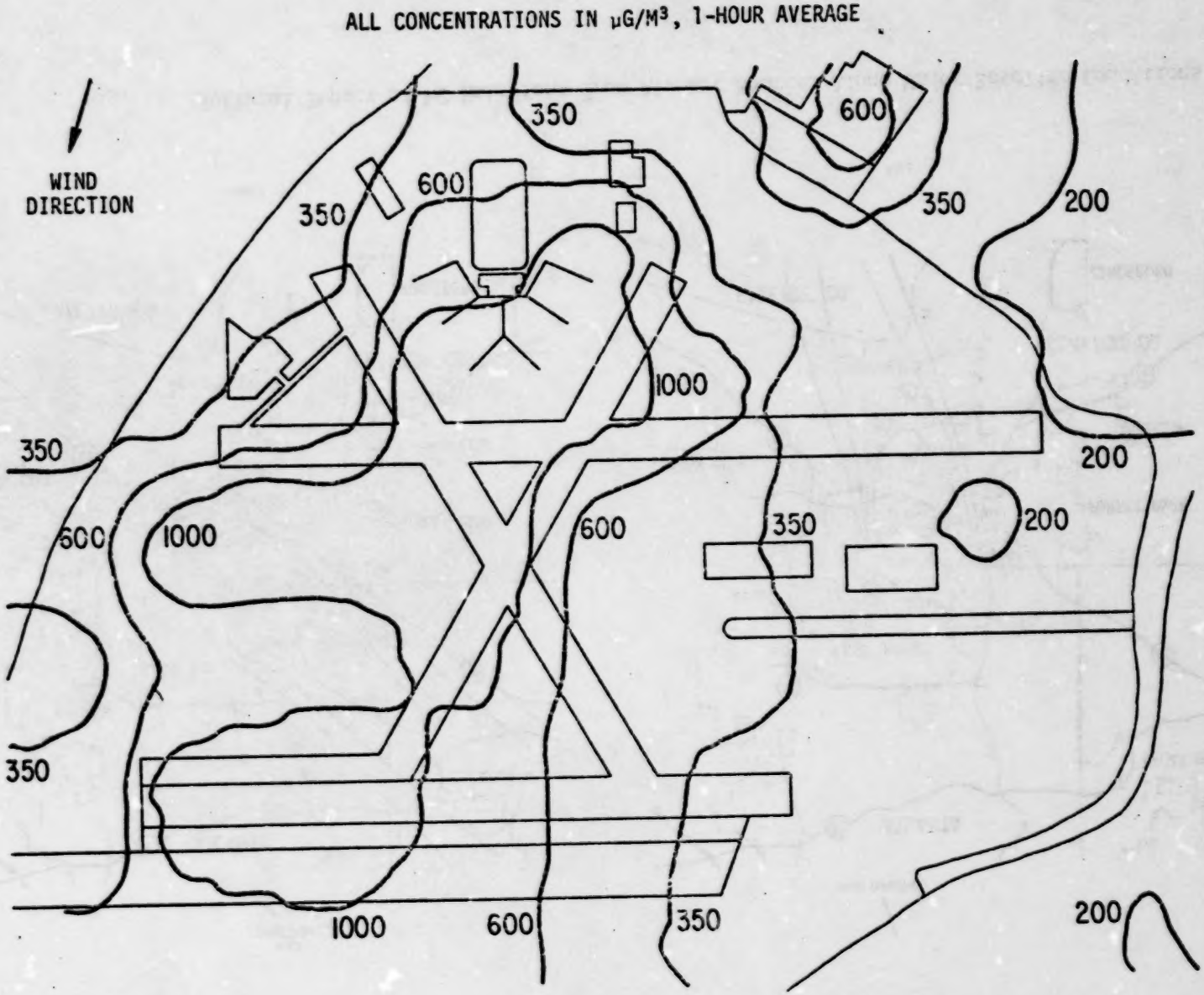


Fig. 11. Airport HC Concentrations for Worst Case Situation, Atlanta

ALL CONCENTRATIONS IN μG/M³, 1-HOUR AVERAGE

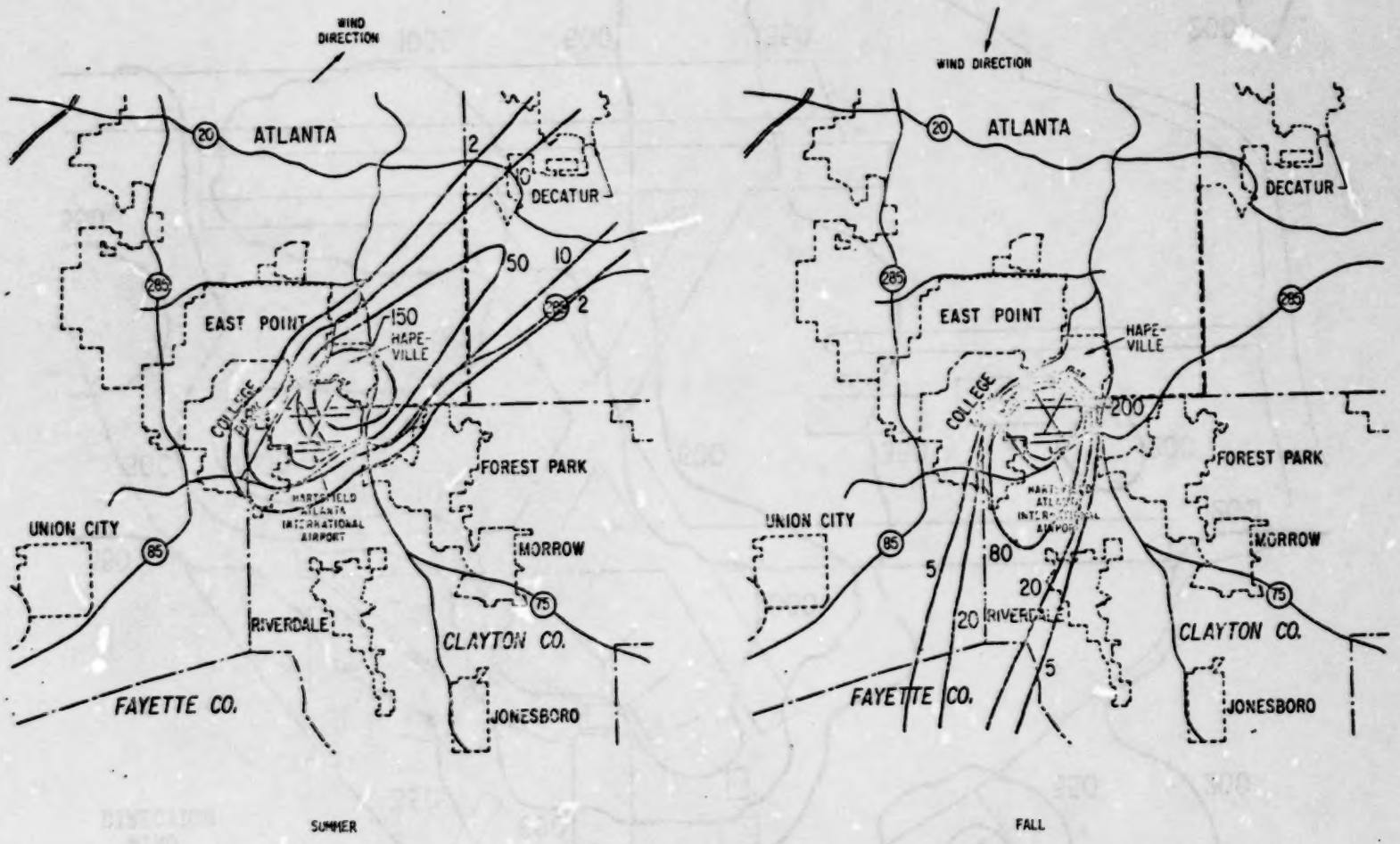


Fig. 12 Regional Impact of HC Emissions from Airport Sources Alone Under Baseline Conditions - Atlanta

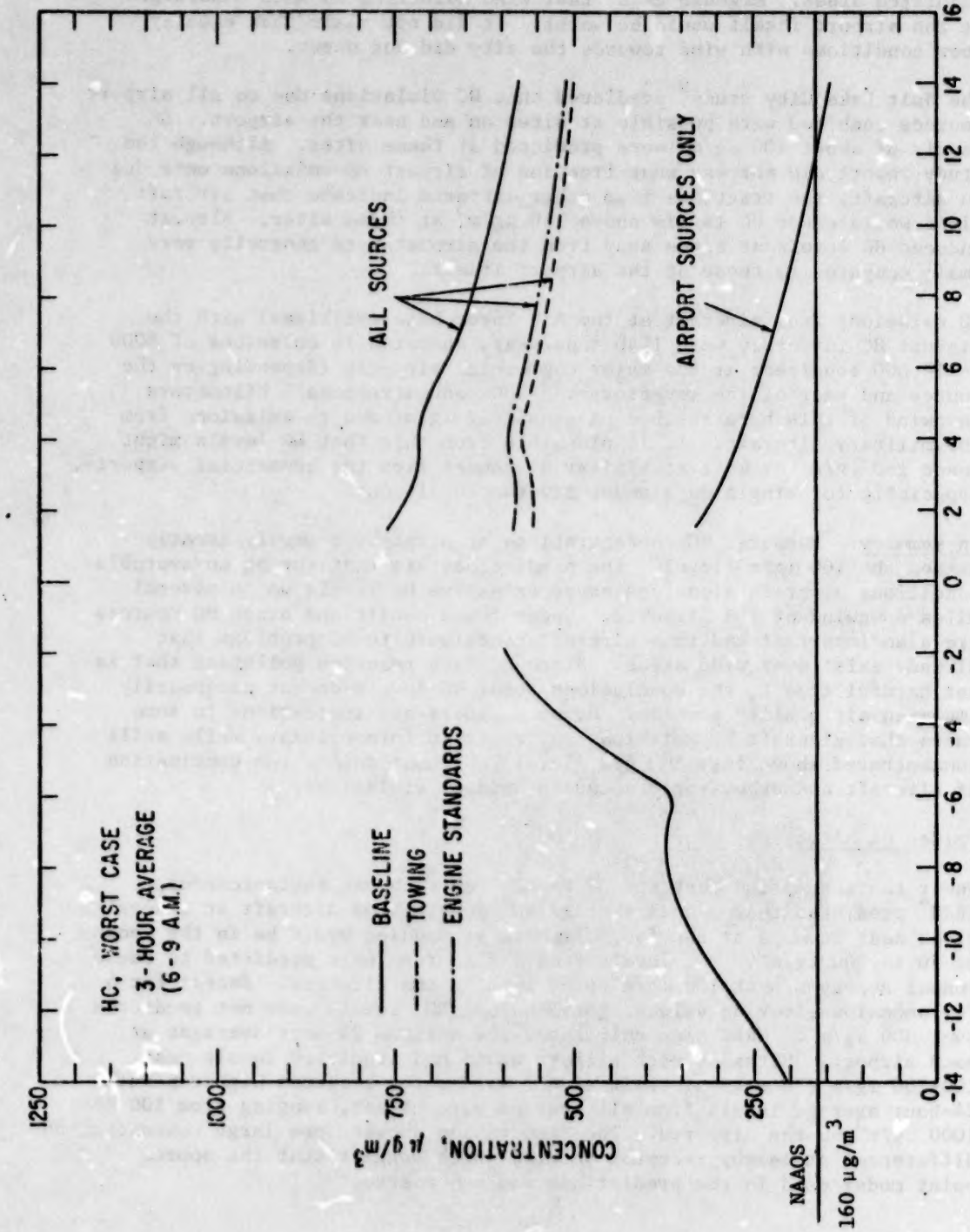


Fig. 13 Regional 3-Hour Hydrocarbon Concentrations Under Worst Case Conditions - Atlanta

contributing significantly to oxidant violations. Note that under the worst case used in the Argonne study, Atlanta itself is upwind of the airport and so the airport emissions do not effect the most heavily populated areas. Argonne chose that wind direction so that conditions at the airport itself would be worst. It did not claim that equally poor conditions with wind towards the city did not occur.

The Salt Lake City study[9] predicted that HC violations due to all airport sources combined were possible at sites on and near the airport. HC levels of about 400 $\mu g/m^3$ were predicted at these sites. Although the study report did not say what fraction of airport HC emissions were due to aircraft, the fractions from other airports indicate that aircraft alone would cause HC levels above 160 $\mu g/m^3$ at these sites. Airport induced HC levels at sites away from the airport were generally very small compared to those at the airport itself.

HC emissions from aircraft at the Air Force base (Williams) with the highest HC inventory were 1540 tons/year, compared to emissions of 5000 to 10,000 tons/year at the major commercial airports (depending on the source and year of the inventory).[15] HC concentrations 5 kilometers downwind of this base reached an annual 22 $\mu g/m^3$ due to emissions from the military aircraft. It is plausible from this that HC levels might reach 160 $\mu g/m^3$ or more at similar distances from the commercial airports, especially for single days under adverse conditions.

In summary: Measured HC concentrations at airports commonly greatly exceed the 160 $\mu g/m^3$ level. The predictions are that during unfavorable conditions aircraft alone can cause excessive HC levels up to several miles downwind of the airports. Under these conditions other HC sources are also important and thus aircraft contribute to HC problems that already exist over wide areas. Since HC is a reactive pollutant that is not harmful itself, the conclusions about HC levels do not necessarily imply an air quality problem. However, there are indications in some cases that aircraft HC emissions may react to form oxidants while still concentrated above the 160 $\mu g/m^3$ level. Without doubt, the combination of aircraft and other sources causes oxidant violations.

Oxides of Nitrogen

Under the assumption that the NO to NO_2 reaction was instantaneous, NREC[4] predicted that annual average NO_2 levels from aircraft at several sites near runways at the four airports it studied would be in the range of 70 to 200 $\mu g/m^3$. NO_2 levels from all sources were predicted to cause annual averages near 100 $\mu g/m^3$ over much of the airports. Except for a few anomalous-looking values, total annual NO_2 levels were not predicted over 300 $\mu g/m^3$. NREC also calculated the maximum 24-hour averages at each airport. Sites at each airport again had predicted levels near 100-200 $\mu g/m^3$, due to aircraft alone, with a few isolated higher points. 24-hour average levels from all sources were higher, ranging from 100 to 1000 $\mu g/m^3$ on the airports. The NREC tables showed some large concentration differences at nearby receptor points, which suggest that the source point model used in the predictions was too coarse.

NREC constructed NO_2 isopleths for L.A. International only, Figures 14-17. Given the known problems with NREC's non-aircraft inventory, Figures 15 and 17 should not be trusted much to indicate anything other than that aircraft on the runways cause NO_2 levels comparable to those caused by the cars in the access road and parking area. Outside the airport itself, the NO_2 level attributable to aircraft is no higher than 10% of the ambient air quality standard.

EPA[5] revised NREC's NOx inventory for L.A. upward to incorporate newer emission factors and constructed new isopleths. These are shown in Figures 18 and 19. The EPA's 1980 emission inventory was too high compared to more recent projections, so Figure 19 should be doubted (see Figure 3). Figure 18 estimates that the residential area near the airport experienced NOx levels between 20 and 50 $\mu g/m^3$ due to aircraft in 1970. These levels have probably increased since then, but not as much as shown in Figure 19.

EPA also constructed an isopleth for O'Hare for 1980. EPA's inventory for this airport and year was reasonably close to its more recent projection (see Figure 4). The isopleth showed that NOx levels from aircraft range up to the 100 $\mu g/m^3$ level outside the airport boundaries.

EPA realized that assuming an instantaneous conversion from NO to NO_2 resulted in overestimates of NO_2 concentrations and so it labeled its isopleths for NOx rather than NO_2.

Geomet monitored[7] NO_2 levels at three sites at Washington National for six months. The monitoring data, summarized in Table 5, indicate that the annual NO_2 standard was violated at all three sites. The maximum and 98th percentile one-hour concentrations are high enough to indicate repeated violation of any likely short term NO_2 standard. Unfortunately, there is no way to determine what fraction of these concentrations is attributable to aircraft.

In developing the AVAP model, Argonne monitored both NO and total NOx at O'Hare. Most measurements were for NOx, but simultaneous NO and NOx measurements were taken at a few sites. One-time NOx measurements at the airport perimeter ranged from 50 to 540 $\mu g/m^3$. Measurements within the airport ranged from 100 to 660 $\mu g/m^3$.

Table 6 shows the measurement results for those sites where both NO and NOx were measured. Very few measurements were made compared to the monitoring at Washington National. The measurements show that little of the ambient NOx was NO at the sites outside the airport, while more was at the sites on the airport. The highest fraction of NO was measured at the terminal area. This pattern agrees in general with the idea that most of the NO emitted from aircraft at the airport remains NO for the time it takes it to disperse away from the airport. Note that in a couple of cases the NO_2 level is high enough to raise concern about violations of a short-term NO_2 standard.

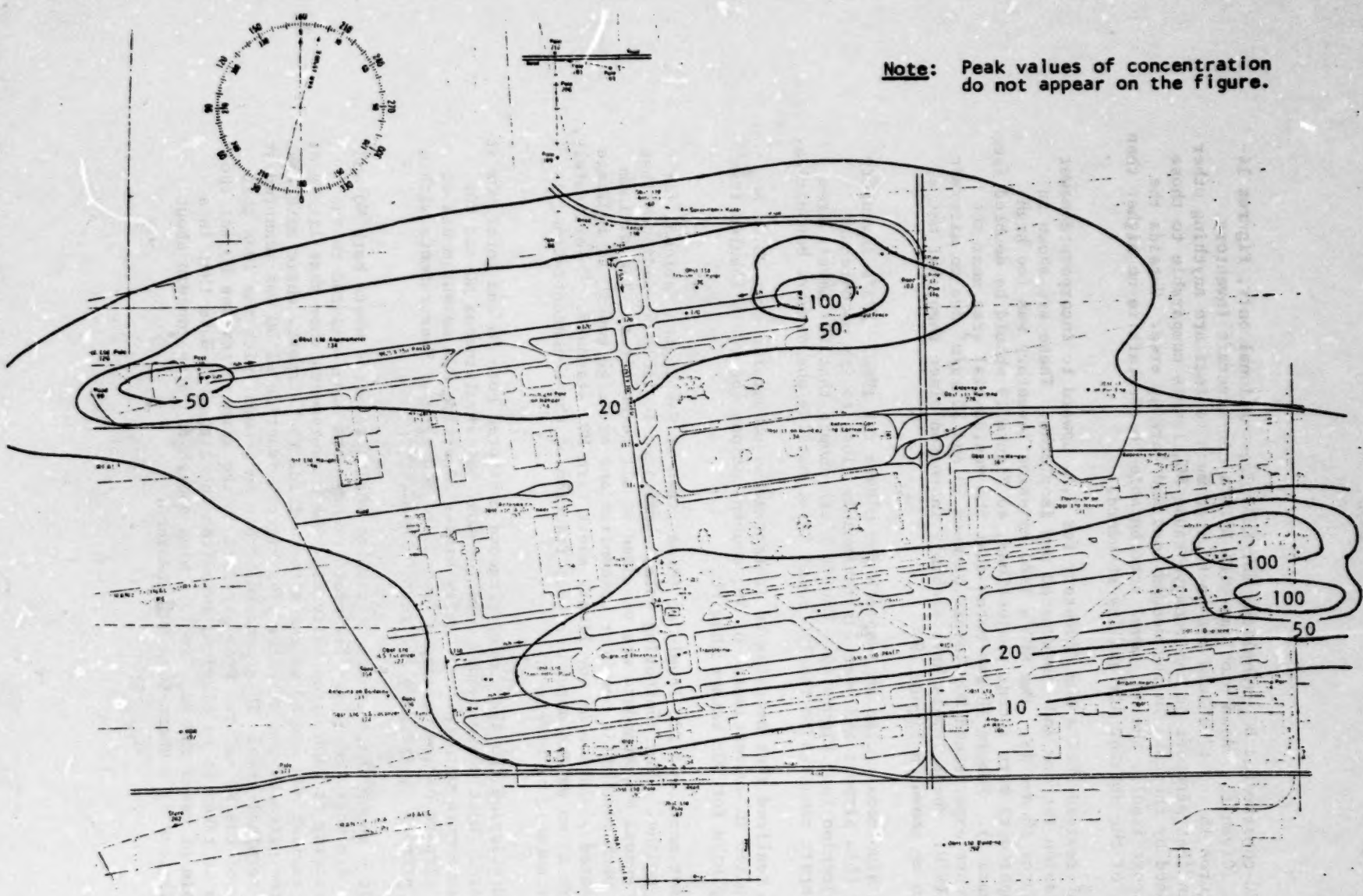


Figure 14. NO_2 Isopleths At Los Angeles International: Aircraft Sources

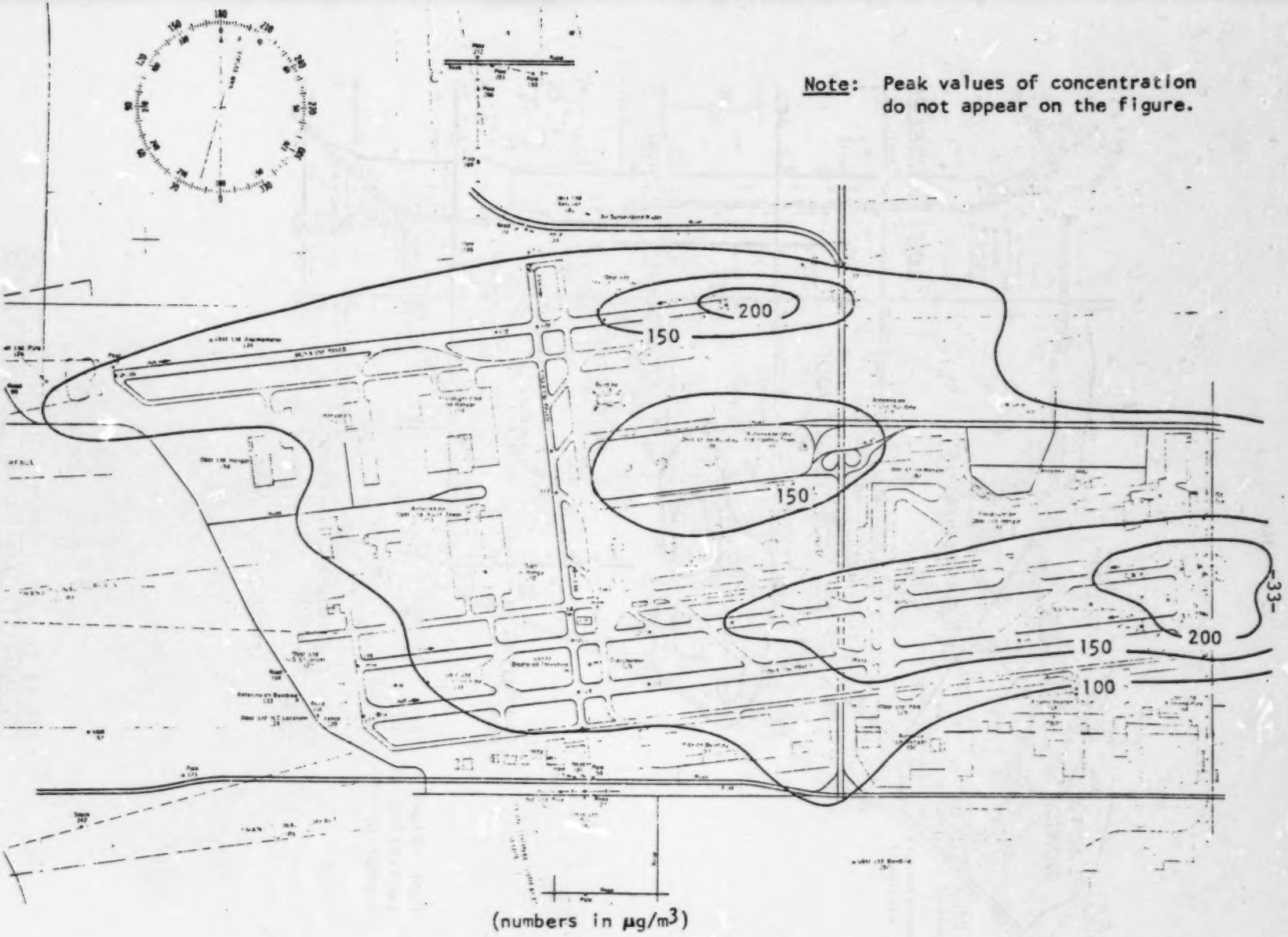
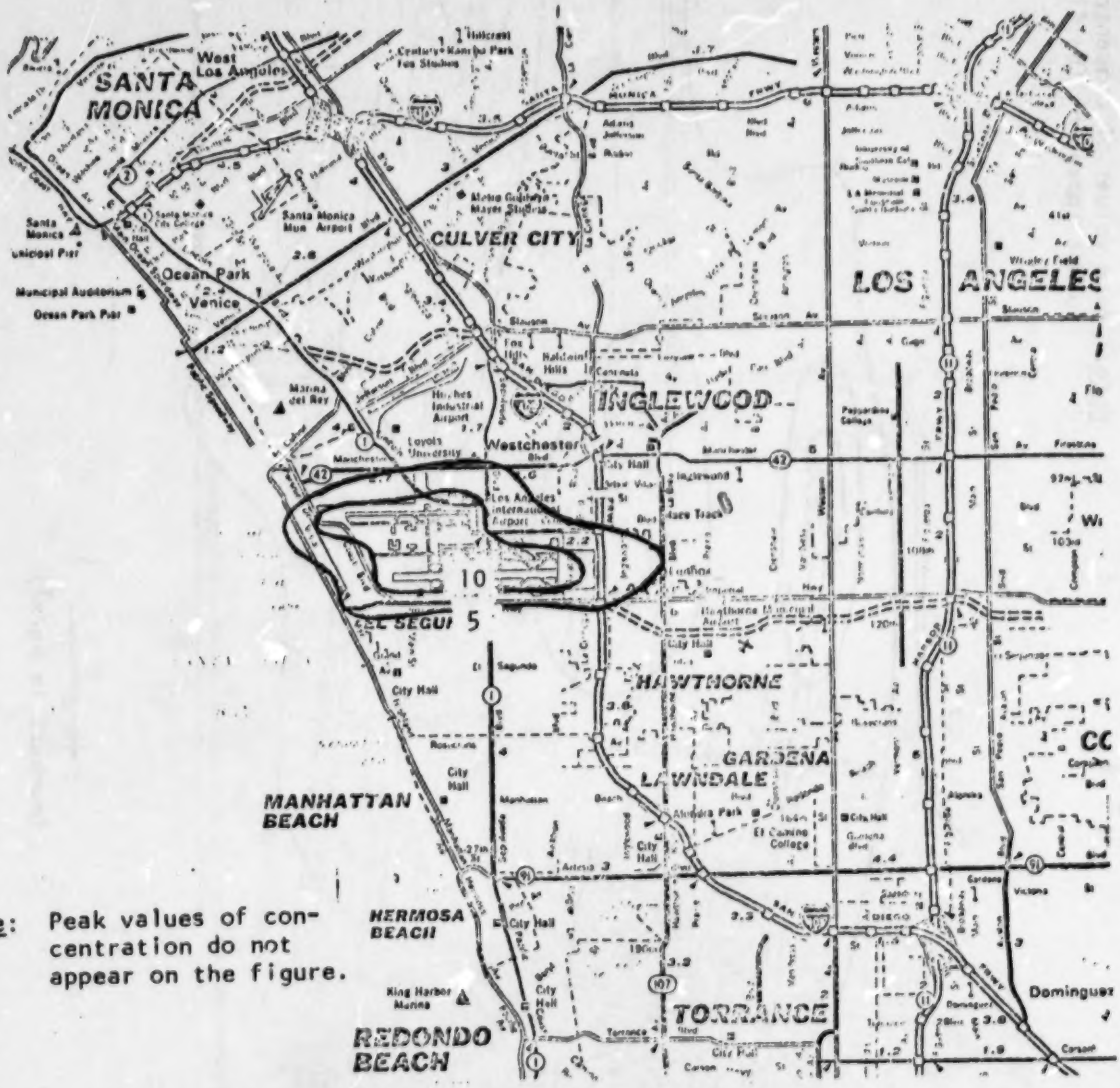


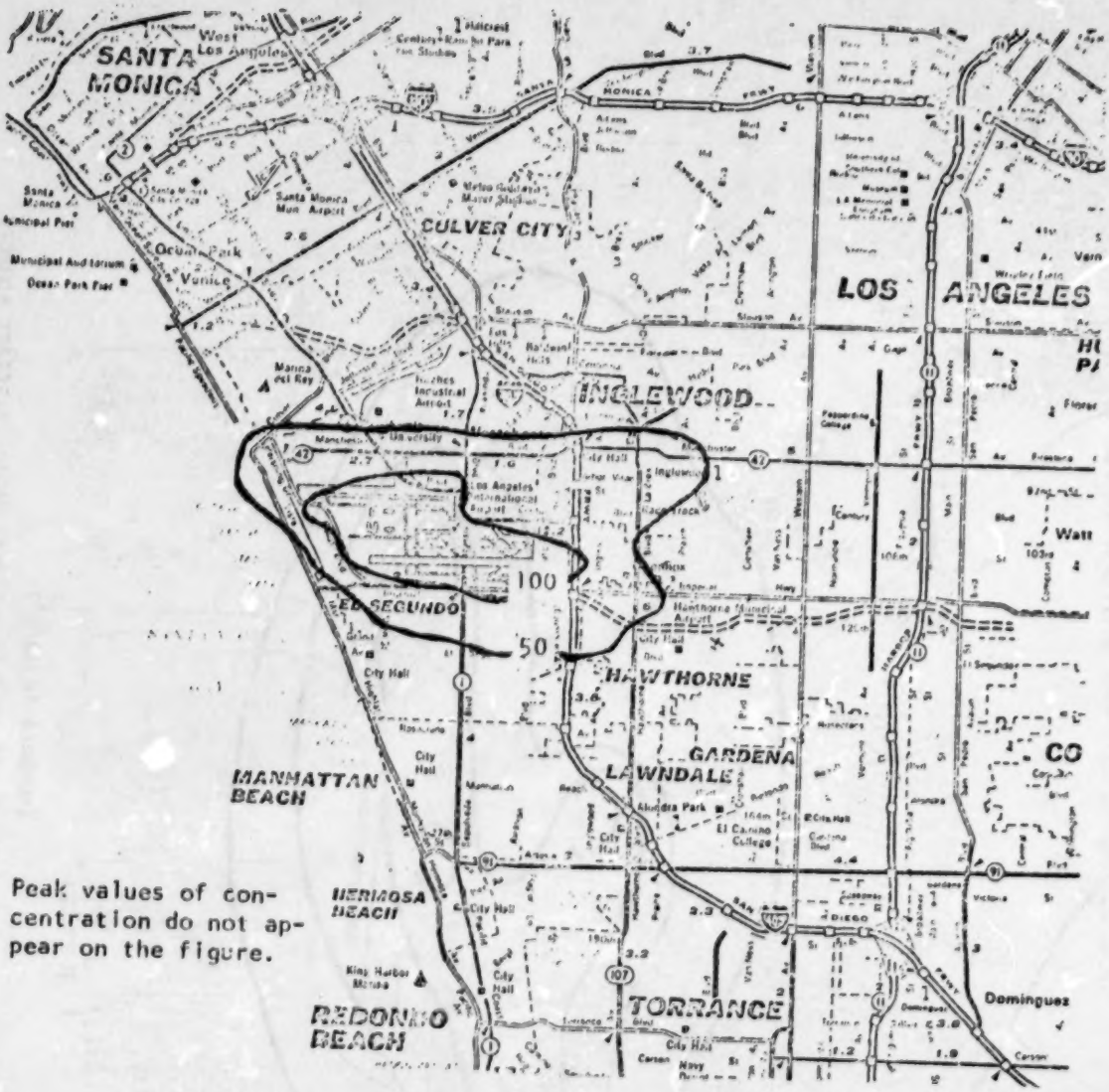
Figure 15 - NO_2 ISOPLETHS AT LOS ANGELES INTERNATIONAL: TOTAL EMISSION SOURCES



Note: Peak values of concentration do not appear on the figure.

(numbers in $\mu g/m^3$)

FIGURE 16 - NO_2 ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES



Note: Peak values of concentration do not appear on the figure.

(numbers in $\mu g/m^3$)

FIGURE 17 - NO_2 ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: TOTAL EMISSION SOURCES

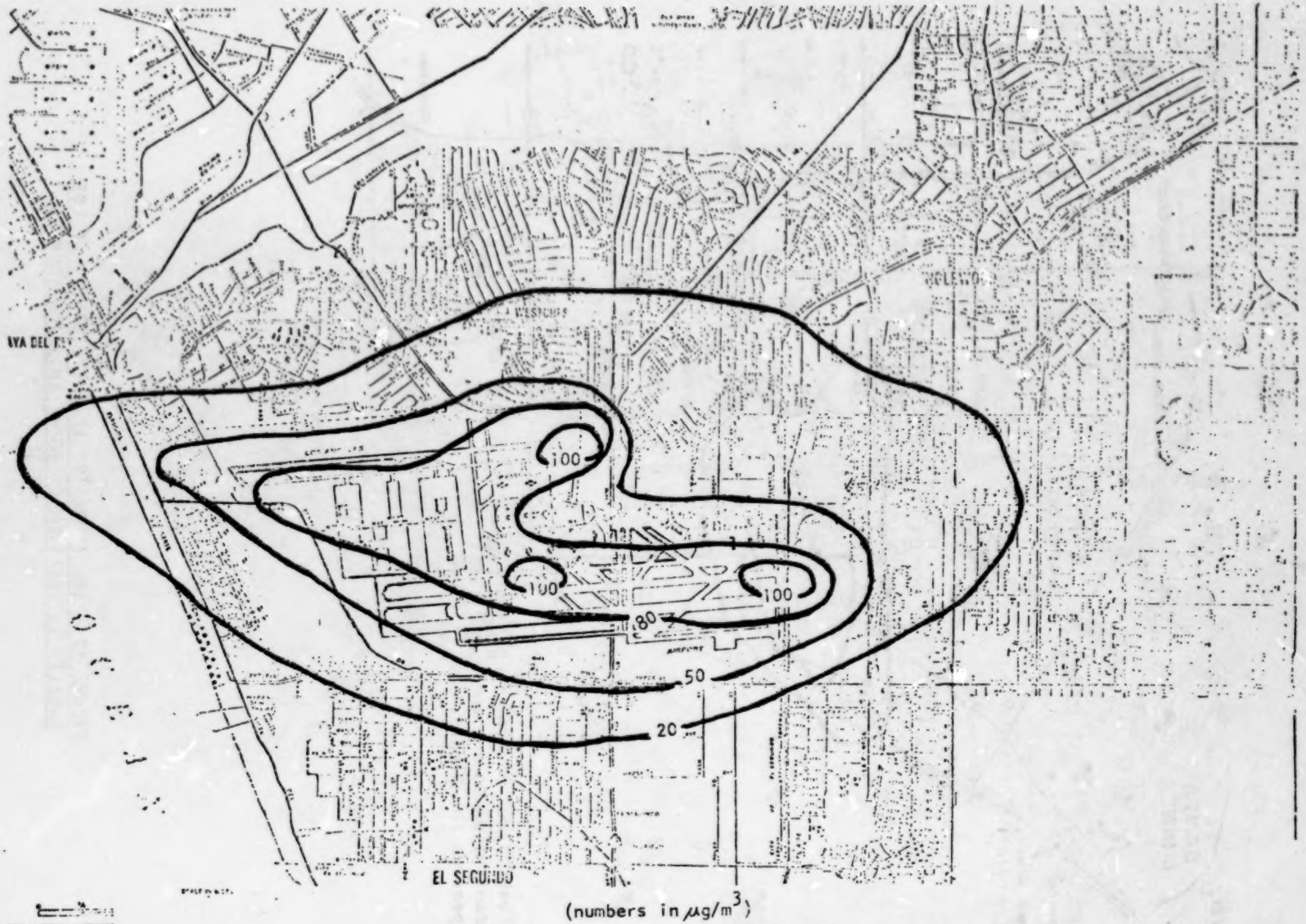
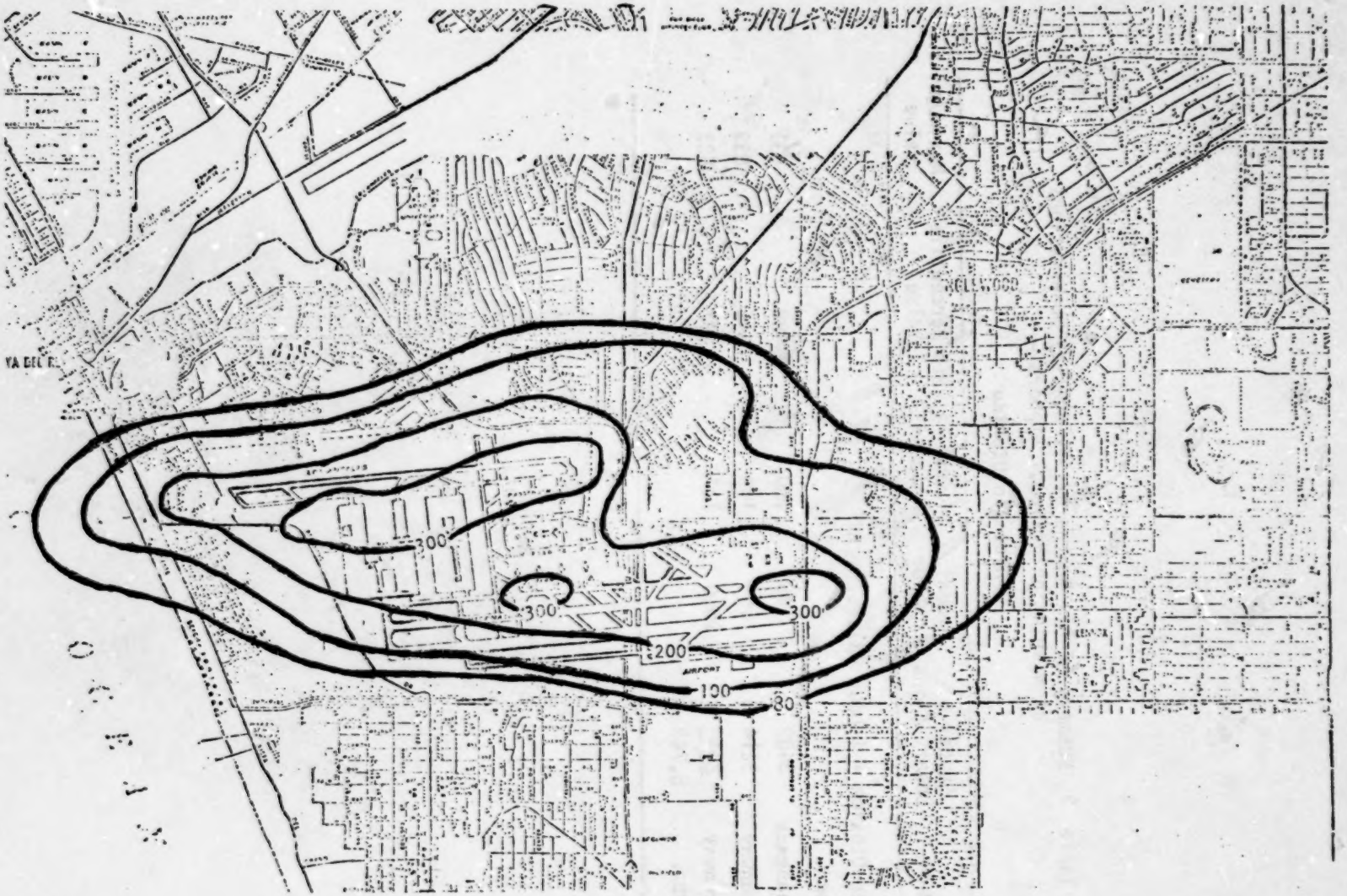


FIGURE 18 NO_x ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES
Annual Average for 1970



(numbers in $\mu g/m^3$)

FIGURE 19 NO_x ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES
Annual Average for 1980

Table 5 Summary of Six Months of Air Quality Observations at Washington National Airport -

Nitrogen Dioxide

Pollutant	Number of Observations	Median Value	Mean Value	98th Percentile Value	Maximum Value
Nitrogen Dioxide - 1-hour values, $\mu g/m^3$					
Station					
2 hangars	3489	145	180	488	631
3 runway	3214	104	149	546	639
6 runway	2040	89.6	127	427	623
Total Obs.	8,743				

Table 6. Results of NO and NOx Monitoring at O'Hare Airport

(Concentrations in $\mu g/m^3$)

Time	NOx	NO	NO_2*	NO/NOx
Receptor No. 1, access road in front of terminal, 12/2/71				
8	134	33	101	25%
9	113	13	100	12
10	93	13	80	14
11	99	27	72	27
12	144	24	120	24
13	134	34	100	25
14	185	56	129	30
15	261	75	186	29
16	274	66	208	24
17-8	227	90	137	40
Receptor No. 4, near end of Runway 14L, 12/4/71				
18	453	74	379	16%
19	453	121	332	27
Receptor No. 5, near end of Runway 9L, 12/7/71				
16	2194	13	2181	<1%
20	1988	27	1961	1
Receptor No. 6, near end of Runway 27R, 12/7/71				
21	185	27	158	15%

Table 6. (continued)

Time	NOx	NO	NO_2*	NO/NOx
	Receptor No. 7, TWA gate G6, 1/11/72			
8	337	148	189	44%
9	200	95	105	47
10	143	81	62	57
11	350	162	188	46
13	181	108	73	60
14-15	100	40	60	40
	Receptor No. 8, Cargo Area, 1/15/72			
11-12	132	1	131	4%
12-13	150	3	147	2
	Receptor No. 21, Eastern Perimeter of Airport, 1/7/72			
16-17	113	14	99	12%
	Receptors No. 33, 34, 35, Suburbs Around Airport			
8-9	49	<1	49	<1%
9	12	<1	12	<1
10	76	<1	76	<1
11	2	<1	2	<1
12	16	<1	16	<1
12	144	<1	144	<1
13	126	55	71	44
14	95	1	94	1
14-15	144	14	130	10
15-16	144	14	130	10

* By subtraction

It would have been interesting to compare the fraction of the NOx attributable to aircraft and the fraction of the NOx that was in the form of NO at each site. Unfortunately, Argonne did not do the modeling calculations that would be necessary for this comparison.

Argonne did use its AVAP model of Washington National to determine the NOx contribution from aircraft.[13] Argonne predicted the NOx concentration from aircraft and the total NOx concentration for a grid of points at National for seven different cases. On two "average-case" days 24-hour NOx levels from aircraft were predicted to exceed the 100 $\mu g/m^3$ level at the ends of runways. NOx levels from all sources exceeded the level of the standard by factors of 2 to 4 over the entire 6.5 square mile grid. On a worst case day, a few more grid points show high 24-hour levels due to aircraft, including a few points over the Potomac River. Argonne's cases included some hourly averages. The grid point values for these can be found in the Argonne report. Generally, with moderate to peak aircraft activity and poor ventilation, NOx levels due to aircraft emissions can exceed the 100 $\mu g/m^3$ over the runways and terminal areas and over a mile downwind of the airport boundary. It appears that pockets with high levels of NOx, four or more times the 100 $\mu g/m^3$ level, can occur on the airport due to aircraft. These are also periods of high NOx levels due to other sources. Argonne's predictions for total NOx concentrations include values up to twice as high as the maximum NO_2 levels measured by Geomet and summarized in Table 5.

Figures 20a and 20b[14] show the first of several NOx predictions made by the Atlanta study. NOx emissions from aircraft at Atlanta in the year of the study were roughly one-half to two-thirds those of O'Hare, JFK, or L.A. International. The changes in the isopleths from Figure 20a to 20b were the result of a hypothesized 45% decrease in aircraft NOx emissions. The reduction affects only the isopleths near the starting ends of runways. Isopleths at the airport boundary are not affected at all, indicating that aircraft NOx emissions make only a small contribution at the boundary. As can be seen in Figure 20a, under normal conditions hourly NOx levels are not very high. Figures 21a and 21b show that downwind of the airport, total NOx emissions from all airport sources (80% due to aircraft) do not raise ambient levels above 100 $\mu g/m^3$. This level only occurs at the downwind edge of the airport. NOx levels due to airport sources drop rapidly with distance; at 8 kilometers, the level is about 20 $\mu g/m^3$.

Under worst case conditions consisting of adverse weather and heavy activity, total NOx concentrations on the airport are high enough to raise concern about violations of a short-term NO_2 standard, Figure 22. However, the model prediction is that with the exception of sites at the end of the runways virtually none of these high concentrations can be attributed to aircraft, even less than could be attributed to aircraft under normal conditions. The low wind speed and shallow mixing depth may explain this. Unfortunately, Reference 14 does not give a graph like that of Figures 21a, b for the worst case conditions. The report

ALL CONCENTRATIONS IN μG/M³, 1-HOUR AVERAGE

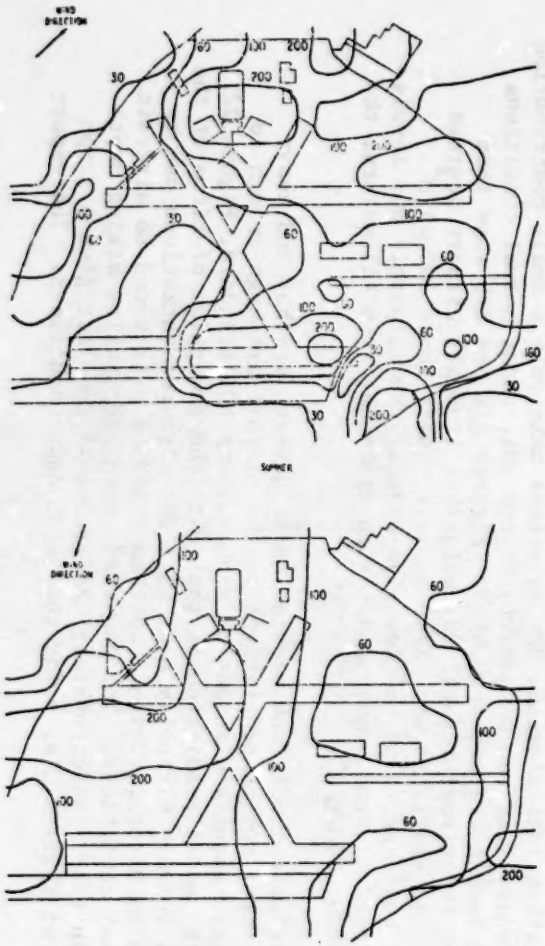


Fig. 20a. Airport NO_x Concentrations for Baseline Conditions - Atlanta

ALL CONCENTRATIONS IN μG/M³, 1-HOUR AVERAGE

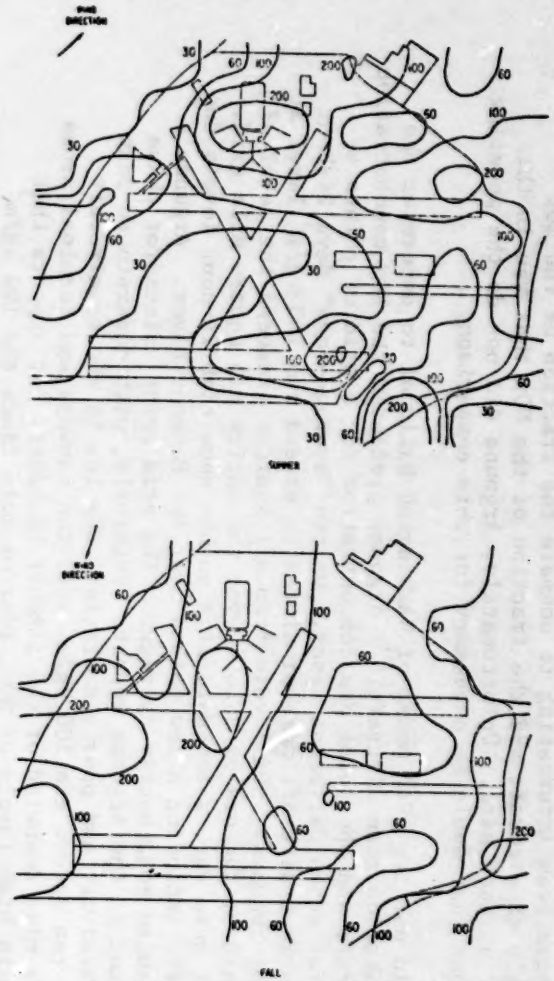


Fig. 20b. Airport NO_x Concentrations for Engine Emission Standards - Atlanta

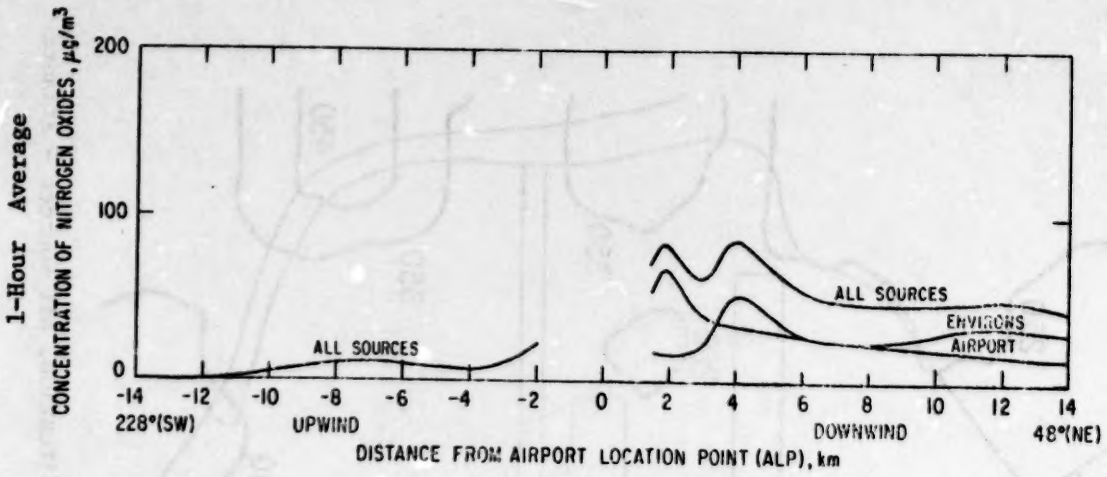


Fig. 21a. Wind Line NOx Profiles Under Baseline Conditions, Summer - Atlanta

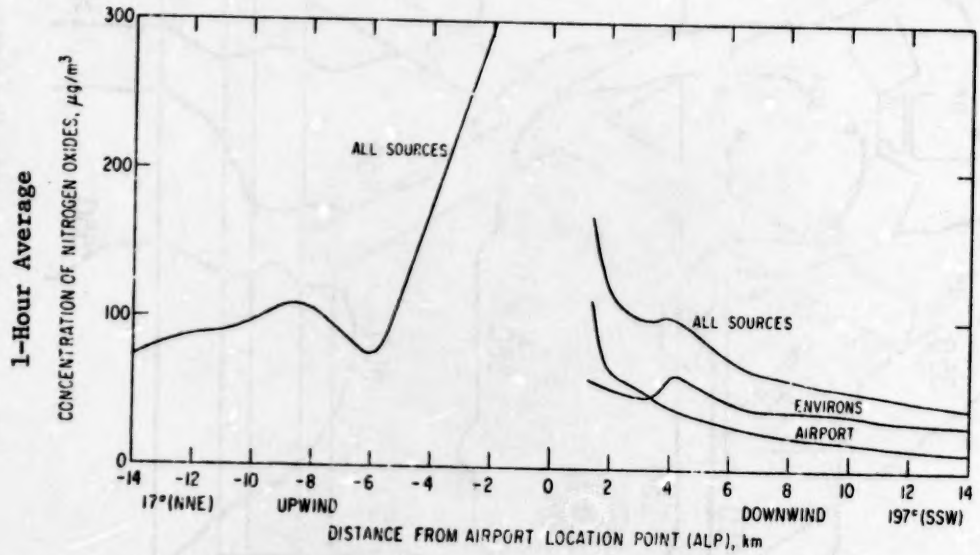


Fig. 21b. Wind Line NOx Profiles Under Baseline Conditions, Fall - Atlanta

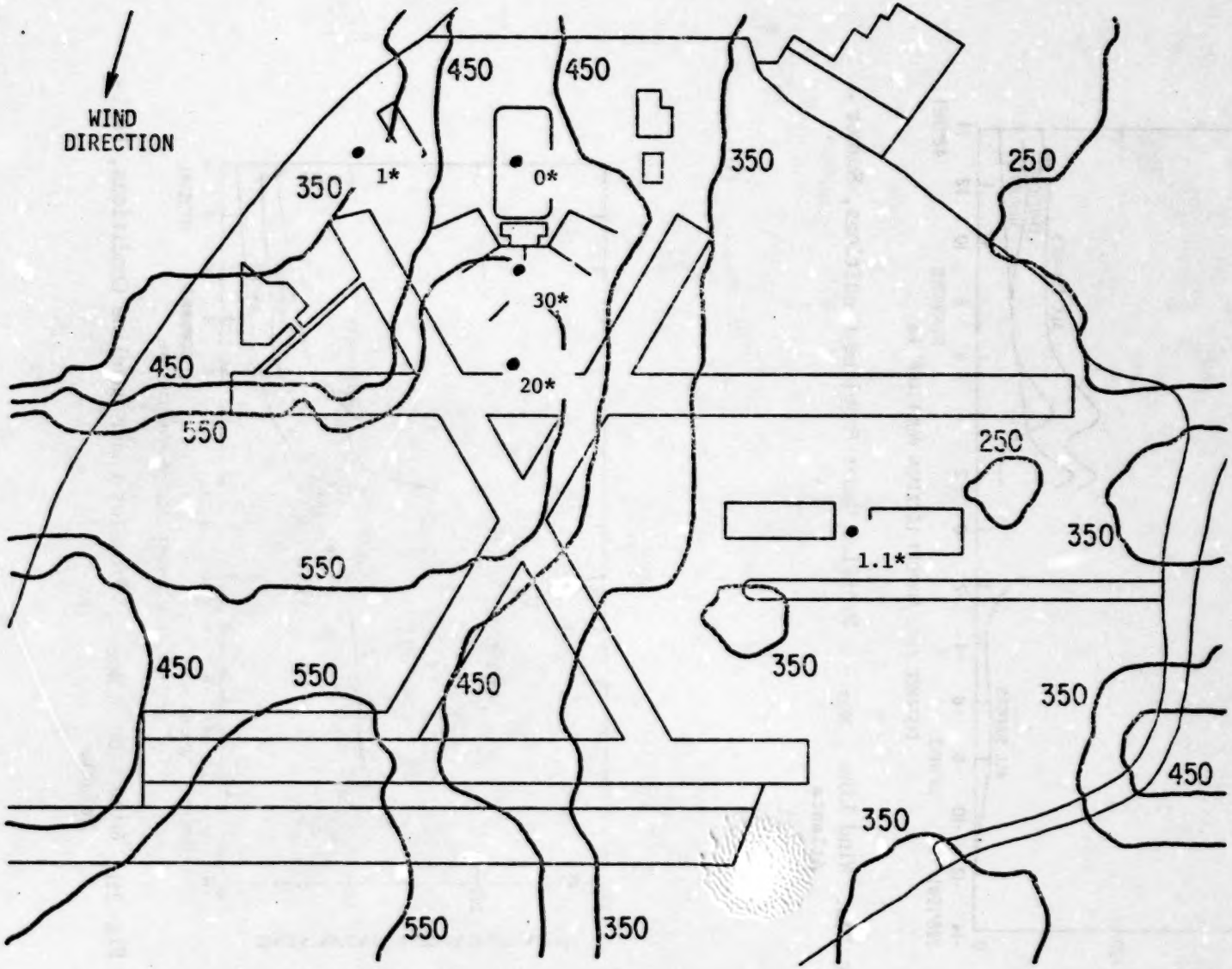


Fig. 22 Airport NO_x Concentrations for Worst Case Situation, All Sources - Atlanta
All Concentrations in $\mu g/m^3$, 1-Hour Average
*Concentration Attributable to Aircraft

does indicate that at 6 kilometers downwind of the airport the NOx concentration from aircraft is about 100 $\mu g/m^3$ and at 14 kilometers it is 88 $\mu g/m^3$. These levels seem inconsistent with the near zero levels predicted on the airport itself, but do seem consistent with the normal case of Figures 21a, b.

Annual average NOx concentrations from all sources also were predicted for the Atlanta airport. The full results can be found in the report from the study or in Reference 1. Briefly, annual average NOx levels were above the standard for NO_2 at two locations on the airport, both near runways. Several other points were within 20% of the standard and the entire airport was above 50 $\mu g/m^3$. The aircraft contribution to annual NOx levels outside the airport was only a few percent of the NO_2 standard.

The Salt Lake City airport has only 15% of the aircraft NOx emissions inventory at Atlanta, but different weather conditions. Using its own model, Geomet predicted[6] annual average NOx concentrations for the airport and surrounding area. Figure 23 is taken from the Geomet report. The figure distinguishes between airport and non-airport contributions to the total concentrations, but does not separate the airport contribution into aircraft and non-aircraft. Assuming an aircraft/non-aircraft split similar to other airports, the aircraft contribution at the Salt Lake City is greater than at Atlanta. The high levels on an annual basis suggest that there is reason for concern about possible violations of a short-term NO_2 standard on and near the airport, depending on the relative speeds of the oxidation and dispersion processes.

In summary: NOx levels due to aircraft have been predicted to reach several times the 100 $\mu g/m^3$ level at several commercial airports, on an annual average basis. The highest levels occur near the ends of runways, a pattern consistent with the fact that aircraft NOx emissions occur mostly during runway modes. The predictions indicate that under adverse conditions aircraft can cause short-term NOx levels above 100 $\mu g/m^3$ a mile or more downwind of the airport boundaries. Under these conditions other NOx sources also contribute substantially to very high NOx levels. Measurements confirm that ambient NO_2 levels from all sources can reach above 600 $\mu g/m^3$ during short periods on the airport itself. The fraction of NOx that is in the form of NO_2 has been shown by measurements to be lower on the airport than in surrounding areas.

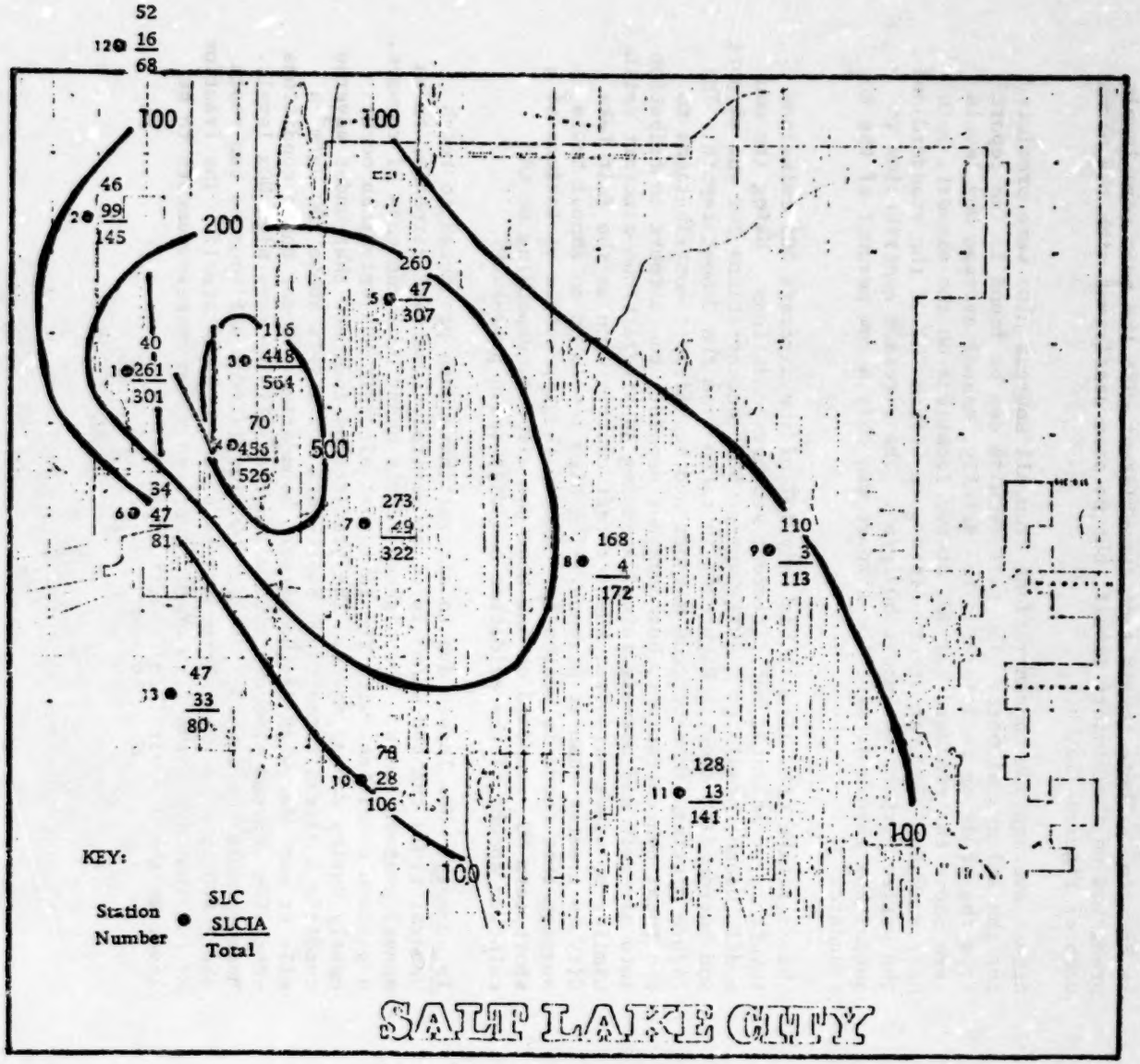


Figure 23. Mean Annual Predicted Values of NO_x showing contributions for airport sources (SLCIA) and non-airport sources (SLC), and totals, in micrograms/cu. m. Contour lines are drawn for totals.

DISCUSSION

Conclusions Regarding Air Quality Violations On and Near Airports

Having reviewed the results of the individual studies it is possible to draw together conclusions about air quality violations in the vicinity of the large commercial airports. In doing so the areas where past studies have been inconclusive will also be apparent.

Carbon Monoxide

Violations of the CO standards have been monitored at the L.A. and Washington airports in areas where aircraft and ground service equipment would seem to be the only significant nearby sources. Violations due to aircraft alone have been predicted at these two airports and at O'Hare and JFK. Both the predicted and monitored sites with high CO include terminal areas where persons have access. Thus, there are at least a few sites at airports where meeting the CO standards requires aircraft emission reductions.

However, there may be more than these few. CO levels have been monitored at only a few sites at a couple airports. The model predictions do not account for obstructions to dispersion which would tend to increase CO concentrations. The model predictions for the patterns of CO levels do not have much spatial resolution except for Atlanta, which apparently does not have any CO problems. Thus it is difficult to tell how much of a terminal area experiences violations. The studies to date do not give much indication of how often each airport has CO problems due to aircraft. And there are many airports which have not been studied at all. Given the known tendency for CO levels to depend on very local emission and dispersion conditions it would not be surprising if smaller airports also had CO problems.

The past studies have also not given a consistent projection of future CO problems. CO emissions have been dropping at some of the airports as a result of fleet mix changes, but projections beyond 1985 are fragmentary. The general indication from the projections that do exist is that CO emissions will either remain fairly constant or increase if no standards are imposed. This suggests that CO problems are not going to correct themselves naturally. It would be desirable to know more accurately how CO emissions will change in the future for each of the top commercial airports. This would give a better indication of whether whatever CO problems do exist now will or will not be alleviated without new controls.

Hydrocarbons

It is clear that aircraft emissions result in hydrocarbon concentrations on the airports that are very high compared to the 160 $\mu g/m^3$ standard. Although the highest of these concentrations occur only over small areas of the airports, the region of concentrations greater than 160 $\mu g/m^3$ can extend several miles past the airport boundaries. When emissions from all sources are considered, the entire area around a major commercial airport can experience very high HC levels.

However, the standard for HC is intended only as a guide in meeting the standard for oxidants. In addition to HC concentrations, time, sunlight, and the presence of NO_2 are required for oxidants to form. Most commercial aircraft operations take place during daylight. Scheduled operations pick up about 6 am at major airports and continue fairly steadily until 8 or 9 pm.[22] Thus sunlight is not in short supply. Neither is NO_2,[18,2] since aircraft emit NOx as well. The Systems Applications study found that the HC/NOx mix in aircraft emissions was in the ozone-producing range. Ozone production is enhanced when aircraft emissions mix with automobile emissions. The time required for the photochemical reactions does affect the conclusions that can be drawn about aircraft-caused oxidant problems.[18] The time required is on the order of a few hours. In this time a given mass of HC moves downwind and disperses to a lower concentration than indicated in the model prediction. There are, however, predicted cases in which high concentrations exist sufficiently far downwind that the HC is concentrated above 160 $\mu g/m^3$ for over an hour. Given the possible errors in the predictions, this suggests that there may be areas downwind of the airports that experience oxidant violations due to aircraft alone. These areas are probably fairly restricted. Too near the airport the pollutants have not had enough time to react; too far away the oxidant has dispersed to below the level of the standard.

Nitrogen Dioxide

Concentrations of NOx due to aircraft are high over the airports and significant portions of surrounding areas. High NO_2 levels have been monitored at airports, but these may have been due to NOx sources upwind of the airport rather than to emissions on the airport itself. Most of the aircraft NOx is emitted as NO and must oxidize to NO_2. As with HC, whether NO_2 concentrations reach high levels depends on the relative swiftness of the oxidation reactions and the dispersion process.

A portion of the NO emitted by aircraft each year escapes conversion while at the airport because it is emitted at night. As Table 7 shows, 35-50% of scheduled operations occur in darkness on days in autumn and 15-30% in days in spring. NO emitted during winter months tends more to disperse before oxidizing because lower temperatures and sunlight intensity result in lower reaction rates. And some NO disperses before it oxidizes even under the most favorable conditions. The EPA Office of Air Quality Planning and Standards has judged that these factors likely combine to result in no violations of the annual NO_2 standard due to aircraft emission alone.

Table 7. Daylight Scheduled Operations As Percentage of Total Scheduled Operations At Five Airports

Airport	Scheduled Aircraft Operations During Indicated Daylight Hours* as Percentage of Scheduled Operations On Given Date	
	November 2, 1973	May 3, 1974
Washington National	65 (6:30am-5:00pm)	85 (6:00am-8:00pm)
J.F.K.	47 (6:30am-5:00pm)	70 (5:45am-7:45pm)
L.A. International	60 (6:00am-5:00pm)	74 (6:15am-7:30pm)
O'Hare	53 (6:15am-4:45pm)	81 (5:45am-7:45pm)
Atlanta	55 (6:45am-5:45pm)	76 (6:45am-8:15pm)

Source: Reference 22

*Daylight hours are approximate local time.

On a short-term basis high NO_2 levels due to aircraft are more likely to occur since conditions favorable to rapid oxidation and slow dispersion will occur occasionally for short periods. The review of the monitoring and modeling results noted several cases in which short-term NOx concentrations were very high. If these occur under conditions favorable to rapid oxidation, short-term NO_2 levels could exceed those that may be specified by EPA if it issues a new ambient standard. The issue of NO to NO_2 conversion is the one least resolved by the past air quality studies and most open to speculation at the present time.

The Regional Perspective

The air quality impact of aircraft emissions alone is only one of the important considerations. There are and will be for some time other emission sources in the region around the major commercial airports. Reference 23 indicates that even with the controls which are now envisioned most cities will still experience violations of the oxidant standard in the year 2000 and the several largest cities will experience NO_2 violations in addition. Thus, even when aircraft would not cause violations they contribute to the severity of already existing violations. Since CO problems are usually quite local and due to motor vehicle traffic, aircraft CO emissions are not of much regional concern. On the airports there may be sites where aircraft CO emissions plus access traffic CO emissions combine to cause localized air quality problems. Oxidants and NO_2 levels, on the other hand, have been found to be more uniform in urban areas, indicating better mixing of emissions. Thus the HC and NOx emissions from aircraft are likely to be contributing to air quality problems over much of their urban areas. This is particularly true for regions like Los Angeles, where more than one-half of the peak NO levels on high NO_2 days are carried over from the previous day.[24] The combination of the different night and day mixing patterns would tend to spread the emissions from any source over a larger area than indicated in any of the airport model predictions.

From a regional perspective, the size of aircraft emissions, the amount they can be reduced, and the cost-effectiveness of controlling them relative to controlling other sources are the three items of interest. Figures 1-4 indicated the range of disagreement about the size of the inventories during the 1970s. References 14, 19, 25, and 26 project emissions past 1980 for some airports; only the latter two consider the case of no aircraft emission standards. The trend shown in Figures 1-4 is that NOx has been increasing during the 1970s and HC and CO decreasing. Part of the HC and CO reduction was due to the almost completed smoke retrofit programs. Changes in fleet mix contributed to the trend also. Figures 24 and 25 show what will happen to the past trend after 1980 at two airports. The figures agree that without controls the decline in HC will end by about 1990 when increases in fleet size overwhelm the trend to larger, cleaner engines.

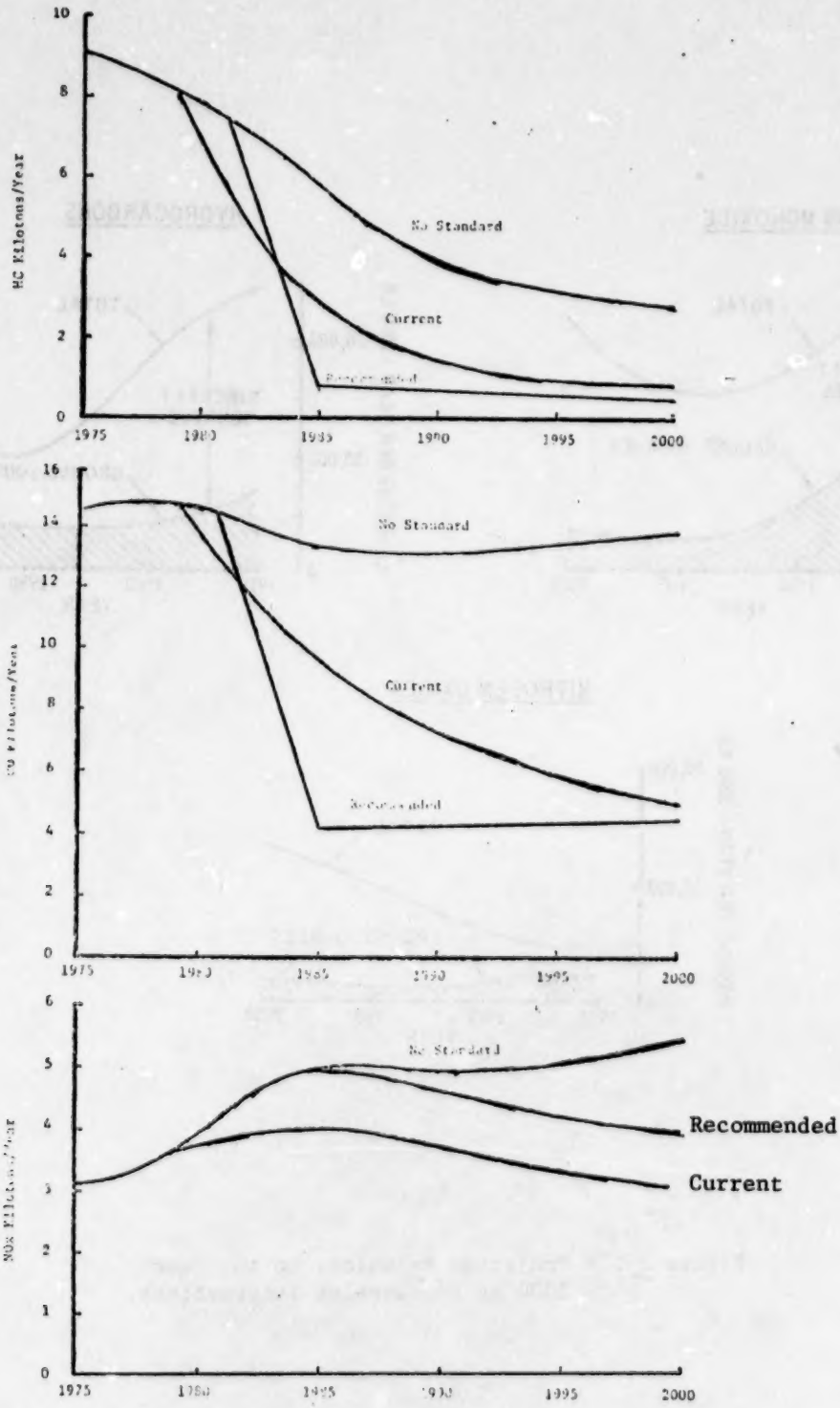


Figure 24. Projected Aircraft Emissions to the Year 2000 at J.F.K.

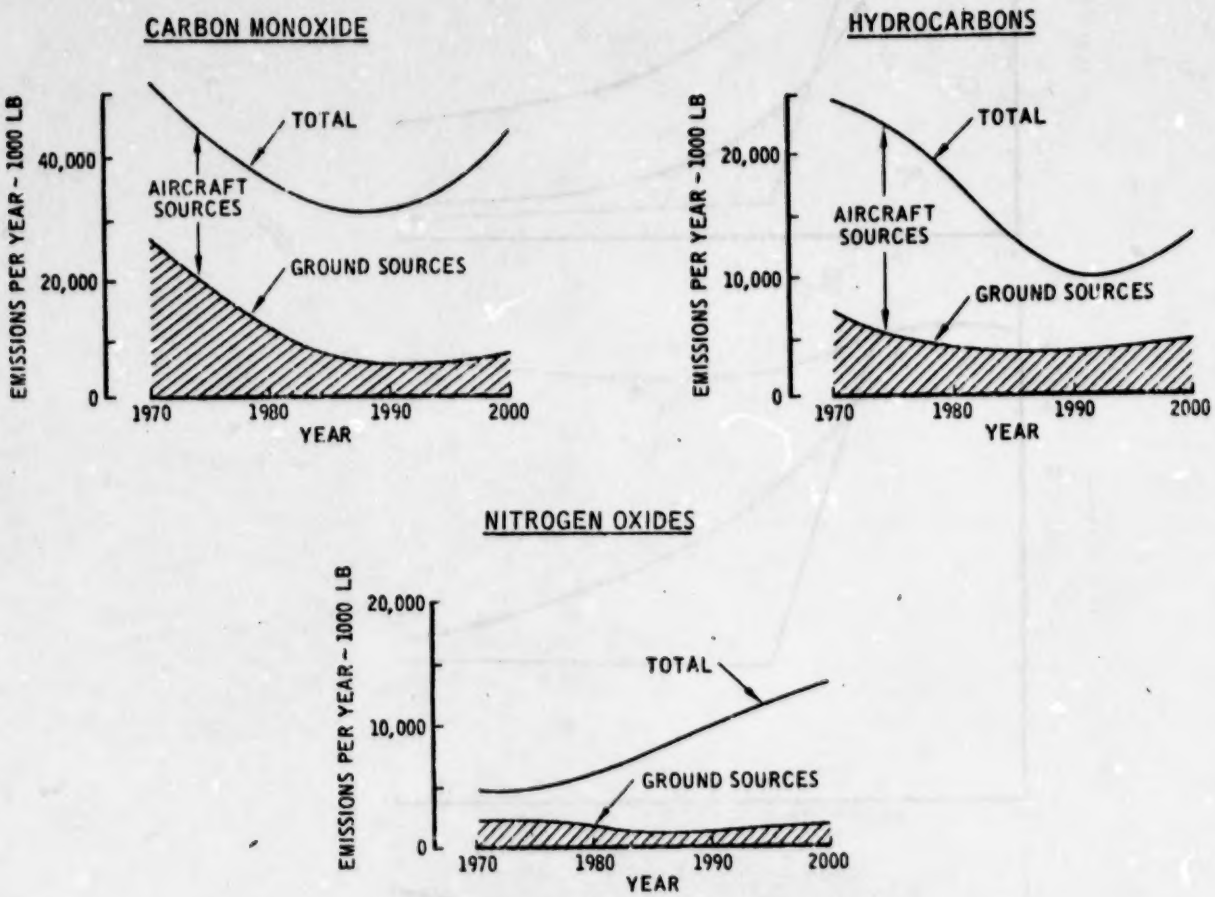


Figure 25. Projected Emissions to the Year 2000 at Los Angeles International

EPA defines a major point source as one with emissions of any one pollutant greater than 100 tons/year. By this definition, aircraft operating at the major commercial airports must be considered very major sources: the estimates shown in Figures 1-4 are in thousands and tens-of-thousands of tons/year. Yet, commercial aircraft contribute only about a percentage point or less of the total emissions in any air quality control region. Tables 8-10 present some data that give a feel for the absolute and relative importance of commercial aircraft emissions. The general conclusion that can be drawn is that commercial aircraft are a significant source of emissions even though their percentage contribution may seem small. This is because a large part of any air quality control region's emissions comes from many small sources.

While total emissions give a first indication of the importance of aircraft emissions, it is the size of the achievable reductions that determine whether controls are administratively worthwhile. Three studies have addressed this question. The Atlanta study[14] calculated the effect the 1979 standards would eventually have on annual aircraft emissions at Atlanta if traffic volume and fleet mix stayed constant. HC, CO, and NOx reductions were 71%, 62% and 45% respectively. These estimates do not hold exactly for the proposed amendments to the standards, because the study accounted for reductions in emissions from non-commercial aircraft and the standards it used for commercial aircraft were somewhat more stringent than the proposed amendments. Figure 24 includes projections of aircraft emissions to the year 2000 for JFK for various control scenarios, as taken from Reference 25. Note that the timing of the emission reductions depends on the scenario. The HC and CO retrofit ("Recommended" curves) advances the date of maximum reduction for those pollutants. Reference 27 estimated the cumulative, national reductions that would result from the proposed amendments. Tables 11 and 12 compare these estimated reductions from aircraft standards to those from other control strategies. Again, the potential reductions from the aircraft standards are small but not insignificant in comparison.

EPA has estimated in a separate report[27] the cost effectiveness of the engine modifications that will result from the proposed amendments and compared its estimates to the cost effectiveness of other control strategies. One of the conclusions reached was that the modifications that will be needed to comply with the proposed 1981 HC and CO requirements for newly manufactured engines and the 1985 HC and CO requirements for in-use engines are cost-effective ways of reducing regional HC emissions. Not enough information on the operating costs associated with the proposed 1984 HC, CO, and NOx requirements is available at present to reach a conclusion on the cost-effectiveness of aircraft NOx controls.

Table 8. Commercial Aircraft Emissions As Percentage of Total Air Quality Control Region Emissions

AQCR	Percent of AQCR Emissions Attributable To Commercial Aircraft		
	CO	NOx	HC
Los Angeles	0.22	0.51	0.41
San Francisco	0.37	0.94	0.84
NY-NJ-Conn	0.32	0.53	0.65
Chicago	0.19	0.55	0.67
St. Louis	0.34	0.30	0.63
Cincinnati	0.14	0.29	0.47
Baltimore	0.32	0.56	0.41
Boston	0.35	0.66	0.64
Houston	0.32	0.47	0.39
S.E. Wisconsin	0.19	0.34	0.18
Washington, D.C.	0.46	0.89	1.11
Atlanta	1.08	2.36	2.50

Source: Reference 28

Table 9. Comparison of Aircraft Emissions With Emissions From Other Mobile Sources - Three Air Quality Control Regions

AQCR	Mobile Source	HC T/yr	CO T/yr	NOx T/yr
Chicago	All Aircraft*	6370	14280	4340
	Locomotives	4030	4780	12860
New York	All Aircraft*	7850	19230	5390
	Merchant Vessels	20580	21920	39240
Detroit (summer only)	All Aircraft*	2325	5360	1289
	Outboards	8440	21640	40

*Includes military, civil, and commercial aircraft. Commercial aircraft dominate in all three AQCR's.

Source: Reference 29.

Table 10. 1973 HC Emissions From Selected Sources in Baltimore AQCR

Sources	Tons of HC
Light-Duty Vehicles and Trucks	86,200
Heavy-Duty Trucks	16,000
Solvent Evaporative Loss	9,700
Gasoline Handling Loss	8,600
Solid Waste Disposal	3,950
Lawn and Garden Equipment	2,000
Vessels	1,300
Off Highway Vehicles	1,200
Locomotives	1,200
Commercial Aircraft	1,023
Residential Fuel	744

Sources: References 20 and 28

Table 11. Comparison of National HC Reductions Achievable With Various Control Strategies, Including Proposed Commercial Aircraft Controls

Strategy: HC Source and Degree of Control	HC Reduction* 1000 T/yr
Degreasing 0-40%	300
Degreasing 41-90%	360
Dry Cleaning 0-80%	480
Refining 0-67%	1530
Arch. Coatings 0-100%	1000
Open Burning 0-25%	300
Paint and Varnish 0-70%	90
Metal Decorating 0-90%	140
Letterpress and Lithography 0-90%	270
Gasoline Handling 16-50%	570
Gasoline Handling 51-91%	680
Gasoline Distribution 67-99%	430
Gas HDV Evap. 5.8-0.5 g/mi	580
LDV Exhaust 0.9-0.41 g/mi	930
LDT and Gas HDV Exhaust 2.9-0.8 g/mi	840
Commercial Aircraft 1981 NME	13.7
Commercial Aircraft 1985 retrofit	35
Commercial Aircraft 1984 NME	103

* For all but aircraft controls, this figure is the reduction in 2000 achieved by imposition of controls now. For 1981 NME controls, this figure is the average annual reduction from 1984 to 1996. For 1985 retrofit controls, this figure is the reduction in 1985; the reduction declines as these already worn engines are retired. For 1984 NME controls, this figure is the reduction in 2000.

Source: References 23 and 27.

Table 12. Comparison of National NOx Reductions Achievable with Various Control Strategies, Including Proposed Commercial Aircraft Controls

Strategy: NOx Source and Degree of Control	NOx Reduction in Year 2000 1000 T/yr
New Utility Boilers 25-50%	3520
Industrial Boilers 25-65%	2460
Old Utility Boilers 25-50%	620
Stationary IC Engines 25-75%	2870
Other Mobile 10-2.0 g/mi	2900
LDV 2.0-1.0 g/mi	1910
Utility Boilers 50-90%	6620
Stationary IC Engines 75-90%	860
LDV 0.4 g/mi	1150
Commercial Aircraft 1984 NME	48.4

Sources: References 23 and 27

When comparing emission reductions and cost effectiveness for mobile and stationary sources it is important to note where the reductions will be achieved. State control of stationary sources can be more selective than EPA control of mobile sources. Some of any reduction in mobile source emissions occurs in areas that do not have air quality problems. But comparatively, commercial aircraft operations tend to take place in major metropolitan areas which tend to be in "problem" air quality control regions. According to Reference 28, 79% of commercial aircraft HC emissions took place in the 79 air quality control regions[23] which experienced oxidant violations in 1973/1974. In comparison, only 64% of light-duty vehicle HC emissions take place in these regions. Twenty-one percent of commercial aircraft NOx emissions take place in the seven regions which had NO_2 violations versus 18% for light-duty vehicles. Compensating the disadvantage of uniform mobile source control compared to selective stationary source control is the administrative advantage of setting and enforcing national standards.

In summary: Even if emissions from commercial aircraft alone do not cause violations of the national ambient air quality standards, they do contribute significantly to present, and future, violations of the oxidant and NO_2 standards in many air quality control regions. The HC requirements of the proposed amendments to the aircraft standards are a cost-effective approach to oxidant control. Not enough information is available to reach a conclusion on the cost-effectiveness of the NOx requirements.

The Planned FAA Air Quality Study

FAA is planning to conduct a new airport air quality study, beginning during the comment period for the proposed amendments. This study will be most useful if it is aimed at complementing the past studies. The findings and failings of the past studies should be considered in setting the goals of the new study.

The FAA study is planned to take 18 months to complete. The study will apply the AVAP model to several airports, the same model used in the more recent past studies. FAA intends to improve on past studies by accounting for non-airport emission sources better. This may allow more convincing validation than with past studies. EPA will participate and intends to give more consideration to issues of photochemical reactions than has been given in past studies. New monitoring data will be collected. Details beyond these are not yet available.

The new study will be the first since the 1971 study by NREC to consider more than one airport. The model it will use is considered more reliable than NREC's. The study may eventually be considered definitive, depending on how many of the unanswered questions it addresses for each airport.

The conclusions that can be reasonably drawn from the discussion of the past studies are (1) aircraft emissions must be controlled to correct CO violations now occuring at a few and possibly more terminal sites, (2) there probably are no annual NO_2 violations attributable to aircraft alone, (3) there may well be violations of a short-term NO_2 standard attributable to aircraft, but there is still a large amount of uncertainty regarding this, (4) there may be areas downwind of airports that experience oxidant violations due to aircraft alone, (5) aircraft HC emission control is a cost effective approach to regional ambient oxidant control, and (6) aircraft NOx emission control has an uncertain cost effectiveness. The new study will contribute to the development of the aircraft regulations only if it affects these six conclusions.

The cost effectiveness conclusion for HC control follows from an analysis of the control technology and not from findings on airport air quality. Consequently, a new air quality study will not change it. The cost effectiveness of NOx control can only be resolved by more complete cost data. A new study could give consistent HC and NOx emission forecasts for a number of airports and control scenarios. This would be an improvement over the few forecasts available now and would give a more exact estimate of the potential improvement in each air quality control region. While better information of this sort is always desirable, the difference between it and EPA's present estimates will probably not be great.

CO is an area where a new study could possibly have an effect. The point of present uncertainty is on how extensive and frequent CO violations from aircraft are and will be. A new set of model predictions may not resolve this uncertainty. The AVAP model does not account for obstructions to dispersion, and these could be important to CO levels. The AVAP study of Washington National did not predict the CO violations monitored by Geomet, for example. Thorough CO monitoring in the terminal areas of several airports would indicate the severity of the CO problem, although the importance of the aircraft contribution could only be inferred from the geometry of each situation. This monitoring would be expensive but the cost would be small compared to the cost of the HC/CO controls.

The possibility of localized oxidant violations attributable directly to aircraft emissions is a minor consideration given the certainty that HC control is a cost-effective approach to reducing regional oxidant concentrations. Thus, there is not much reason for a new study to spend much effort on the question of oxidant violations attributable to aircraft.

The area of present uncertainty with the greatest potential of being brought closer to resolution by a new study is the one concerning short-term NO_2 levels. The uncertain cost-effectiveness of aircraft NOx controls and the relatively few regions which experience annual NO_2

violations make the efficiency of the controls simply as a way of achieving regional annual average NO_2 air quality uncertain. If aircraft NOx controls are needed to prevent or reduce violations of a short-term NO_2 standard, that will be the stronger argument for the controls. Thus the need for NOx controls may hinge on short-term NO_2. This is the area most open to speculation at present. The AVAP model to be used in the new study does not predict short-term NO_2 levels. But more relevant analysis of the AVAP results could be made than has been in past studies. Monitoring of NO and NO_2, when combined with model predictions on the fraction of NOx from aircraft, may shead more light on how much of the aircraft NO oxidizes the NO_2 before dispersing. Better inventories for non-airport NOx emissions should improve model predictions of the fraction of NOx from aircraft. The actual NO/NO_2 composition of aircraft exhaust should be determined also, either through measurement or kinetic modeling. The NO/NO_2 composition is known for some engines but not all.[18] No studies have been made of how much additional oxidation of NO to NO_2 takes place in the high temperature, high concentration exhaust plume.

In summary: The new FAA study should devote its attention to resolving present uncertainties concerning the effect of aircraft emissions on localized, short-term CO and NO_2 concentrations. Monitoring will be just as crucial to resolving these uncertainties as will dispersion modeling.

CONCLUSIONS

The 1971 study by Northern Research and Engineering[4] was the most comprehensive of the airport air quality studies. Unfortunately it was also probably the least accurate, certainly the least demonstrably accurate. If the argument for emission controls on commercial aircraft depended only on the 1971 NREC study and the 1972 EPA report[3] it would be weak. However, more recent studies by both EPA and FAA have confirmed some of the NREC conclusions and added others. These have been summarized in the Discussion section of this report.

Very briefly, CO violations attributable to aircraft are occurring at at least a few terminal gate areas and at the ends of runways. The areas of high CO attributable to aircraft are not extensive, but can include areas where persons have regular access. HC emissions from commercial aircraft create regions of high HC concentrations that include the major commercial airports and the areas several miles downwind. NOx emissions create smaller regions of high NOx concentrations, but ones that still extend beyond the airport boundaries.

The past air quality studies do not provide an answer to the question of whether NO_2 and oxidant violations can be attributed to aircraft. This is because they have not been able to consider the photochemical processes by which these criteria pollutants are formed from HC and NOx. It seems reasonable that on an annual basis most of the aircraft NOx disperses from the airport before it can oxidize to NO_2. On a short-term basis, only judgment is available at present and that suggests that the chances of short-term violations are much better than for annual violations.

Oxidant violations on the airport due to aircraft could only occur under stagnant conditions. With a wind, the area of violation would be well downwind of the airport. However, it is reasonable to assume that even in the relatively far future (at least to the year 2000) aircraft HC emissions will be in addition to those from other sources and that the total will cause widespread oxidant problems in most American cities. Aircraft HC controls are a cost effective way of helping to reduce this oxidant problem. In particular, the HC/CO retrofit program is the only control strategy which reduces aircraft HC emissions in the near future.

The desirability of the modifications that would be forced into use by the HC standards is reasonably well demonstrated in the results of the past studies. Further study of HC will not contribute to the development of the amendments to the existing standards. There is still some uncertainty about the number of localized areas which are experiencing CO problems because of commercial aircraft. Monitoring of CO levels at a number of airport terminals would help resolve this uncertainty. There is a great amount of uncertainty and speculation about the need for aircraft NOx controls, as this largely hinges on the contribution of

aircraft to short-term NO_2 levels. Past studies have not considered this question in any depth.

The new air quality study should attempt to resolve the two areas of present uncertainty by concentrating on short-term, localized CO and NO_2 air quality. CO monitoring will be more definitive than CO modeling. Monitoring should also include both NO and NO_2 in order to help resolve the questions of how quickly aircraft NO oxidizes to NO_2. A study which is not designed to effectively address the CO and NO_2 questions will be a minimal contribution to the development of the aircraft amendments.

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